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STABILITY ENHANCEMENT OF PRODUCTS FROM GULF'S COAL BENEFICIATION PROCESS

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SUMMARY

The Gulf two-stage beneficiation process thermally treats low rank coals at 350°C and upgrades the dried products with petroleum residuum. Typical products using high volatile bituminous coals from the Gulf Process are low in moisture content, free from dust problems, with good appearance and possess equilibrium moistures in the range of 5-7%. The commercial application of this upgrading process relies heavily on demonstration of product stability towards autogenous heating.

This research contract investigates three stabilization options to achieve this objective. Product stability enhancement by incorporating carbon dioxide conditioning, heating in steam environment, and product moisture adjustment in the Gulf Process is demonstrated. The results of this research contract reveal important findings in the future development of low rank coal upgrading technology.

Only partial demonstration of product stability was possible due to the inconsistency of oxygen sorption test data which appear to be affected by many factors. The results of this study show that the criteria used in the assessment of product stability, oxygen sorption, carbon monoxide and carbon dioxide production, are related to the moisture contents and residuum contents of the products, sample history, and the elapsed time between sample production and the sorption test. Qualitative correlations of oxygen sorption, carbon monoxide and carbon dioxide production with these factors were examined in this program.

Over the range of variables tested in this study, the results show that oxygen sorption is proportional to product moisture content and inversely proportional to residuum content of the upgraded products. Both carbon monoxide and carbon dioxide production are proportional to oxygen consumption. However, product moisture content affects these interrelationships.

The different effects of elapsed time on oxygen sorption data observed for products from normal operation and from stabilization options can not be quantified. However, understanding this effect could be beneficial in the further development of low rank coal upgrading technology. It appears that there is a time-dependent stabilization mechanism when the products are generated under carbon dioxide conditioning and thermal treatment in a steam environment.

Moisture sorption by upgraded products in a constant temperature humidity environment is a reliable method of assessing the moisture sorption capacity of the upgraded products. This, in turn, might provide a good indication of potential problems due to heat of wetting during sample stockpiling or storage. Under an environment of 21°C and 75% relative humidity, an upgraded product of 4-5% moisture content is stable with respect to moisture sorption and desorption. A method to generate a product of these controlled moisture contents with 5% residuum content needs to be proven. Products from the Gulf Process with or without stabilization options show similar moisture sorption capacities.

1.0 INTRODUCTION

This report describes work performed during 1989 on D.S.S. contract 06SQ.23440-8-9034, "Stability Enhancement of Products from Gulf's Coal Beneficiation Process".

The primary objective of this research contract is to improve the stability of upgraded products towards autogeneous heating. Three stabilization techniques were used: steam heating, carbon dioxide conditioning, and adjusting the moisture contents of the upgraded products. The effects of these stabilizing options were examined individually and collectively in a systematic manner.

Two methods were used to evaluate the stability of the upgraded products: moisture sorption and oxygen sorption at ambient temperature. Moisture sorption provides an indication of heat generation due to heat of wetting. Oxygen sorption together with carbon monoxide production supply the data on the reactivities of the upgraded products towards oxidation. Low temperature oxidation and heat of wetting are the two major factors governing spontaneous combustion.

This research contract consists of seven tasks with the following specific objectives:

1. To characterize the feed coal in terms of quality and stability.
2. To modify the heat source of the beneficiation pilot plant to allow thermal treatment of coals in a steam environment.
3. To investigate product stability from the Gulf Process by varying the product moisture contents, using steam heating, and applying carbon dioxide conditioning, individually and collectively.
4. To critically evaluate the data of product stability.

The results of this research contract are discussed in detail in this final report. The work statement for this research contract is presented in Appendix 1.

2.0 EXPERIMENTAL

This section describes the equipment, the steam heating system, product characterization, and the methods used in this research contract to evaluate product stability.

2.1 Gulf's Two Stage Coal Beneficiation Process

A two stage coal beneficiation process was used in this research contract. The first stage involved heating the coal. The second stage involved applying the residuum. The overall process configuration is shown in Figure 1. The pilot plant consists of the following components.

Heat Source and Control. The heat source was natural gas. The combustion gases passed through the heating drum and were then exhausted to the building's Roto-Cone air scrubbers. Fines entrained in these exhaust gases were not recovered. A thermocouple inserted in the exhaust gases at the discharge end of the heating drum was used to control product temperature. Typically, the set temperature of the exhaust gases was 130 - 150°C above the desired coal temperature of 350°C. When the set temperature was reached the natural gas would shut off for either 7 or 45 seconds, depending on how quickly the exhaust gases cooled.

Heating Drum. The heating drum was 1.6 meters in length and 20 centimeters in diameter. 2.5 centimeter lifters ran the full length of the drum with the exception of the initial 16 centimeters where helical flights served to slow down the incoming feed. Drum angle and rpm's could be varied to control residence time, which was approximately 10 minutes in a typical experiment.

Feed rate was controlled by an electromagnetic vibratory feeder. Coal feed rate was typically 36 kg/h. Product from the heating drum discharged through a chute into an insulated transfer auger which transported the hot product to the feed end of the treating drum. The amount of insulation and auger speed could be varied to control, within limits, the temperature of the coal entering the treating drum.

Transfer Auger. This 10 cm diameter by 150 cm long auger was used to transfer the hot coal from the heating drum to the feed end of the treating drum. The auger was insulated to reduce heat loss. The auger was inclined at approximately 45 degrees. Coal residence time was typically four minutes, but could be varied by changing the auger speed by means of the electronic variable speed control.

The hot coal from the heating drum fell into the auger hopper by dropping down an open chute. Hot product from the treating drum was sampled as it fell from this chute (T_1). Similarly, the coal exiting from the auger fell through the air a short distance before entering the treating drum feed chute. This provided a sampling point for the partially cooled heating drum product (T_2). The difference between the two temperatures was typically in the range of 70-120°C.

Residuum Injection System. The residua were heated to about 300°C in a 5 litre container. Heat was supplied by a hot plate as well as by electrothermal heating tapes wrapped around the container. A Bran and Lubbe metering pump was used to deliver the hot residuum to the treating drum. The pump and a stainless steel tubing injection line (1 meter long and 0.95 cm diameter) were heat traced and insulated. The injection line projected about 10 centimeters inside the feed end of the treating drum. The hot residuum fell directly onto the tumbling bed of coal.

Treating Drum. The treating drum was 0.8 meters long, 20 centimeters in diameter, and had eight equally spaced 2.5 centimeter lifters running its length. Drum rotation was controlled by an electronic variable speed controller. Typical residence time was four minutes.

The treating drum product discharged into steel sample containers (or the product auger for the water cooling tests) where final product temperature was determined (T_3).

Product Auger. The product auger was identical to the transfer auger and also had electronic variable speed control. The base of the product auger sat in a

pool of water which kept the product auger's feed hopper partially filled with water. The pool of water was continuously replenished with fresh water which flowed over the outside surface of the product auger, thereby cooling the auger and the product it was transporting. Products produced in this manner are identified as water cooled products in this report.

The cooled wet treated product exited from the product auger into bulk containers or sample containers (T_4).

2.2 Steam Heating System

In order to evaluate steam heating as a means to improve product stability the burner system and the combustion zone of the heating drum were modified to allow maximum steam flow and minimum oxygen content in the heating drum. The modified system was capable of achieving an exhaust gas temperature of 490°C, which was required to produce a coal drying temperature of 350°C in the beneficiation experiments.

The modification consisted of changing the settings of the regulator for the natural gas, the position of the damper fan for the combustion air, and injecting steam at 125°C available from the Coal Research Centre in Devon. The settings were extensively calibrated (Appendix 2) so that combustion could be carried out at minimum level of excess air (hence minimum level of excess oxygen). The steam was injected at the tip of the flame of the burner to increase the temperature of the steam. The optimum condition was developed by monitoring the temperature of the exhaust gas in the heating drum.

The operating conditions of the steam heating system are presented in Appendix 3. The thermal efficiency of the steam heating system, and the concentrations of steam and the combustion gases are also shown in Appendix 3. The steam heating system resulted in a volumetric flow of heating medium containing 72.7% steam, 0.3% oxygen, and 27.0% of carbon dioxide combustion gases and nitrogen. This system is essentially oxygen free and was used for the beneficiation experiments to evaluate the benefits of steam heating.

2.3 Product Characterization

The coal feedstock and all the upgraded products prepared in this reserach contract were characterized for residual moisture, equilbrium moisture and product residuum content. Residual moisture content was determined in accordance with ASTM specification D3172; equilibrium moisture was analyzed according to ASTM D1412 with modifications. Product residuum content was determined by solvent extraction. The modified methods and procedures used for equilibrium moisture and product residuum contents are described below:

2.3.1 Equilibrium Moisture

The equilibrium moisture determination procedure was essentially the same as that specified in ASTM D 1412 with one difference: the true size consist was used instead of the minus 1.18 mm size fraction recommended by ASTM. This change was made because the residuum coating was supposed to seal the outer pores of the particles. Crushing the coated coal would expose fresh untreated surfaces. By using the full size consist the chances of error were increased due to sample heterogeneity. This potential problem was compensated for by increasing the weight of sample used per determination, 14-15 grams compared to 4-5 gms recommended by ASTM. Test duration was 96 hours, which was longer than required for the Obed coal. The longer time was used because it was felt that the residuum on the products would slow down the rate of moisture sorption.

2.3.2 Product Residuum Content

Representative product samples were pulverized to minus 60 mesh (0.25 mm). Approximately 3-4 grams of the pulverized sample was placed in a cellulose thimble and a standard Soxhlet Extraction with methylene chloride was used to determine the residuum content on the product. The amount of residuum was calculated by subtracting the final weight of dry extracted sample from the initial weight of moist, residuum coated sample, and then accounting for the moisture content of the sample.

2.4 Assessment of Product Stability

The fundamental factor affecting the stability of a coal sample towards autogeneous heating is low temperature oxidation. Both the reactivity and the kinetics of the low temperature oxidation process are related to sample characteristics such as coal structure and surface area available for oxidation. The kinetics of the oxidation process can be significantly affected by the moisture content. Heat of wetting, generated during moisture sorption, can greatly increase the temperature which accelerates the oxidation process to the extent of sustained combustion.

The stability of the products generated in this research contract was assessed based on two mechanisms: oxygen sorption and moisture sorption at low temperature.

These methods for stability evaluation were chosen due to the lack of facilities for monitoring temperature rise during storage, and due to the fact that the quantity of the samples are too small to conduct a meaningful stockpile monitoring test. The two methods used in this research contract are described below.

2.4.1 Moisture Sorption

In this test, 200 gram samples were placed in a constant environment, 75% relative humidity and 21°C, and the weight change was determined at 24 hour increments up to 96 hours. It was assumed that the greater the moisture sorption and the faster the rate of sorption, the less stable the product would be. In essence, this test was a form of equilibrium moisture test done at a relative humidity and temperature selected to be representative of the environment that commercial products would be subjected to.

2.4.2 Stability Tests

The stability tests were done by CANMET's Coal Research Laboratory, Devon, Alberta. The tests were non-standard in that they were designed to handle full size consist coal. The tests measured a coal sample's ability to absorb oxygen and to generate carbon monoxide, CO, and carbon dioxide, CO_2. From the results it was inferred that the higher the oxygen sorption, expressed as ml's absorbed per 100g of sample, and the higher the CO and CO_2 production, expressed in ppm, the more reactive or less stable the coal. The test procedure was as follows:

- Remove 1.5 kg of sample from its sealed container.
- Place 1.5 kg sample in steel cannister of known volume (approximately 21.5 litres).
- Seal cannister and pass moist air through cannister for 5 minutes.
- Allow cannister and sealed sample to sit for 96 hours (isothermal).
- At the end of 96 hours sample head gas in the cannister and analyse using gas chromatograph.
- Calculate oxygen sorption and CO and CO_2 production values based on final and initial conditions.

The method used to calculate sorption of oxygen and production of carbon monoxide and carbon dioxide is shown in Appendix 4.

3.0 ANALYSIS OF FEEDSTOCKS

The feedstocks (coal and residuum) used in this research contract were obtained from a previous Gulf-CANMET contract 06SQ.23440-7-9197, "Fundamental Support to the Development of Gulf's Coal Beneficiation Process". To maintain the same feedstocks is essential in process technology development. The analytical data of these feedstocks are also readily available.

3.1 Coal Sample

The Obed sample was a dryer feed sample from the Obed coal preparation plant. Top size was reported to be 12.5 mm but some oversize was present. Accordingly, the Obed sample was screened through a 19 mm opening screen and the undersize was used. Table 1 presents the size distribution of the Obed coal used in the testwork. The sample was stored in sealed nitrogen purged drums until required for testing.

The proximate, ultimate, and equilibrium moisture analyses of the Obed coal are provided in Table 2. The difference between total moisture and equilibrium moisture is considered to be surface moisture. Thus, the Obed coal had 2.8% surface moisture. The surface moisture of the Obed sample was sufficient to cause flow problems when feeding the heating drum. Consequently, the coal feed rate fluctuated significantly during the tests using Obed sample.

The equilibrium moisture value reported in Table 2 is higher than the value normally reported for Obed coal, (11.5%). Typically, coarser fractions exhibit lower equilibrium moisture values. Thus, equilibrium moisture values determined for full size consist Obed coal are lower than the values determined for the minus 19 mm fractions used in this program.

3.2 Residuum Sample

Cenex PDA obtained from a deasphalt unit from Cenex in Montana, was used as the residuum in coal beneficiation. This was the residuum used in many Gulf-CANMET Research contracts and was used in a mine-mouth demonstration project at the Obed Mountain Coal Company.

The physical and chemical properties of the Cenex residuum are summarized in Table 3.

4.0 BENEFICIATION EXPERIMENTS

This section describes the experimental design, heating media, cooling methods, product treatment for different product moisture levels, and the operating conditions used in the beneficiation experiments. The objective of these experiments was to investigate the effect of these stabilization options (steam drying, carbon dioxide conditioning, and moisture levels of products) on product stability, in a systematic manner.

4.1 Experimental Design and Experimental Series

The experimental design of this research contract is summarized in Table 4. A total of 32 products in duplicates representing 16 different processing conditions were obtained in the experimental program. Four experimental series were performed:

Series 1 - Base Case (8 samples)
Drying by combustion gases, cooling by air followed by nitrogen purge, and adjusting moisture levels.

Series 2 - CO_2 conditioning (8 samples)
Drying by combustion gases, cooling by CO_2 followed by nitrogen purge, and adjusting moisture levels.

Series 3 - Steam Heating (8 samples)
Drying by steam and combustion gases with minimum oxygen content, cooling by air followed by nitrogen purge, and adjusting moisture levels.

Series 4 - Steam Heating and CO_2 conditioning (8 samples)
Drying by steam and combustion gases with minimum oxygen content, cooling by CO_2 followed by nitrogen purge, and adjusting moisture levels.

4.2 Heating Media

Two heating media were used in the experimental program of this research contract: combustion gases and steam with combustion gases. In the first case, the oxygen content in the combustion gases was about 5%. In the steam heating case, the oxygen content was reduced to 0.3 vol% by using minimum amount of excess air and injecting steam to maintain an exhaust gas temperature of 490°C. The concentration of steam under this condition was about 75 vol% in the heating drum. The differences in the oxygen concentration in these heating media were used to study the effect of the inert atmosphere on product stability.

4.3 Cooling Methods

Cooling of the products was achieved by using air, carbon dioxide or water as the cooling media. It has been reported that carbon dioxide can be absorbed very rapidly by thermally dried coals (3), thus preventing oxygen sorption which leads to oxidation of the upgraded products. Water cooling can also be used to produce a product with a higher moisture content which may also improve product stability.

Typically, the products were cooled in either air or carbon dioxide to ambient temperature and then split into subsamples for moisture adjustment. The subsamples were purged with nitrogen for an extended period and stored in double plastic bags. When water was used as the cooling medium, products from the treating drum were submerged in water immediately, and purged with either nitrogen or carbon dioxide after being removed from the water.

4.4 Product Moisture Adjustment

The adjustment of moisture contents of products from air or carbon dioxide cooling was achieved by adding a known quantity of water to the subsamples and allowing the mixtures to reach equilibrium. The samples after the moisture adjustment were reanalyzed for moisture content before the stability evaluation

test. This method of adjusting product moisture was used because there was no practical method of controlling the moisture content of the products from the water cooling tests.

There was no readjustment of the moisture contents of the water cooled products.

4.5 Operating Conditions

All the experimental series were conducted at a target coal feed rate of 36 kg/hr. A target residuum content of 4 wt% was set in these experiments. Coal temperature in the heating drum was typically 350°C, and the product temperature exiting the treating drum was between 160° - 180°C. The operating conditions for all the experimental series are shown in Table 5.

5.0 PRODUCT CHARACTERIZATION

All the upgraded products (in duplicates) from the four experimental series were characterized for equilibrium moisture, residuum content, and product moisture content. These characterizations are considered to be adequate in the evaluation of process performance and product qualities. The results of product characterization are presented in Tables 6 to 9.

5.1 Equilibrium Moisture

The data collected from the operation of the two stage Gulf process indicate that equilibrium moisture of the upgraded products is mainly controlled by process temperature, but is also dependent on residuum content (4). At a processing temperature of 350°C for coal in the heating drum, untreated products (no residuum) generally show equilibrium moistures in the range of 7-8% (4), whereas upgraded products with 4-5% residuum typically have equilibrium moistures in the range of 5-6%. The results in Tables 6 to 9 confirm the previous observations for residuum treated coals.

Two series of beneficiation experiments performed during the commissioning of the steam heating system also confirmed these observations. These two series of experiments were carried out to investigate if lower temperature can be used in a steam environment in the thermal treatment of low rank coals. At an exhaust gas temperature between 410-450°C, the equilibrium moistures of the upgraded products were in the range of 7-9%, significantly higher than equilibrium moistures of 5-6% when the exhaust gas was raised to 480°C. These two series of experiments were excluded from the project but the data are presented in Appendix 5 for reference.

5.2 Residuum Content

Due to the lack of fine control of the residuum pump (2), some variations in the residuum contents on the upgraded products were observed in the experimental series. Products generated in this research contract show a residuum content from 3 to 6%. Higher residuum contents generally give lower equilibrium moistures for

the upgraded products. Residuum contents also show a large effect on the initial product moisture of the water cooled products and on the moisture sorption of the products (Section 6).

5.3 Moisture Content

Upgraded products at four different moisture levels were produced in duplicates in each experimental series. These products are identified as zero % moisture product, 4% moisture product, 8% moisture product, and the water cooled product. The actual moisture levels of the upgraded products from the experimental series are shown in Tables 6 to 9.

The zero % moisture products are essentially bone dry materials. They are the "normal" products from the two stage Gulf process. Both the 4% and 8% moisture products are "manufactured" products, generated by adding known amounts of water to the normal products and allowing the mixtures to equilibrate for a period of at least two weeks. The actual moisture contents of the 4% moisture products are in the range of 3 to 4%; but the actual moisture contents of the 8% moisture products are usually in the range of 5 to 7%. The extremely hydrophobic nature of the residuum coated products meant that any surface water drained off the coal was collected in the bottom of the sample bags. This made collection of a representative sample for moisture determination virtually impossible. This is the primary reason that the moisture contents as analysed are significantly less than the moisture contents based on water addition.

It should be mentioned that while these products are reported to have certain moisture levels, the nature of the water forced back into the coal pores in these experiments may or may not be the same as the water remaining when a coal sample is naturally dried to these moisture levels.

Water cooling was used as a method for product cooling and also for moisture adjustment. Since only a short period was used in this cooling process,

the moisture contents of the water cooled products were difficult to control and were dependent on the residuum contents of the products. Products of higher residuum contents in the duplicate tests in each experimental series gave lower moisture contents for the upgraded products. The fact that residuum made the products more hydrophobic was evident from these experiments.

6.0 EVALUATION OF PRODUCT STABILITY

The stability of the upgraded products towards autogenous heating was assessed by the moisture uptake and the oxygen sorption methods. The results of these evaluations are discussed in this section.

6.1 Moisture Sorption Test

Moisture sorption by the upgraded products was monitored at 21°C and 75% R.H. in a constant temperature environmental chamber. These conditions are considered to be more representative of the environment in actual coal storage and stockpiling. The initial moisture content of the coal sample was first determined in this test; then weight gain or loss of the sample at every 24 hour interval was added or subtracted from the initial moisture values. The results of the moisture sorption test for all the upgraded products in the experimental series are shown in Tables 10 to 13.

6.1.1 Moisture Sorption

Figure 2 presents the moisture sorption curves for the four upgraded products in the original "A" test series in the base case. Products of four moisture levels were subjected to this moisture sorption test: A zero moisture product (0.0%), 4% moisture product (3.2%), 8% moisture product (6.25%), and a water-cooled product (4.15%). The figures in the parentheses show the actual initial moistures of these products. Under the environmental conditions used in this test, Figure 2 clearly shows that the zero moisture product rapidly picked up moisture. Moisture sorption by the 4% product and the water-cooled product proceeded at much slower rates. The 8% moisture product released moisture in the first 24 hours and stabilized after this initial period. It should be noted that while the moisture sorption test can be considered as a test for equilibrium moisture at 75% R.H., the products with similar ASTM equilibrium moisture contents did not reach the same moisture level in 72 or 96 hours.

Moisture sorption for the products in all other experimental series exhibit a similar trend as shown in the base case.

6.1.2 Effect of Residuum Content on Product Moisture Sorption

The moisture sorption curves for all the upgraded products (in duplicates) in the experimental series are presented in Figures 3 to 6. These curves show the effect of residuum content on the initial moisture contents of the water cooled products (Section 5.2) and moisture sorption by products in the environmental chamber test.

The effect of residuum content on the initial moisture contents of the water cooled products are summarized in Table 14 for each experimental series. A higher residuum content gave a lower initial moisture content in the water cooled product. In the experimental series of steam heating followed by CO_2 cooling, initial product moistures are 3.3% and 0.4% at residuum levels of 3.8% and 5.6%, respectively. These trends are observed in all the other experimental series conducted in this research contract.

The effect of residuum content on moisture sorption by the products was shown to be most significant for the zero % moisture products in all the experimental series. Very significant differences in the "rates" of moisture sorption by the zero % moisture products are observed. In the experimental series of steam heating and CO_2 cooling, the zero % moisture product with residuum content at 3.7% picked up 4.6% moisture in 72 hours, whereas the same product at 5.2% residuum content showed a moisture sorption of only 2.7% in the same period. These trends are observed for all the experimental series and are illustrated in Figures 3 to 6.

The large differences in moisture sorption in the zero % moisture products do not occur for products of higher initial moisture contents. However, the final moisture contents of the products are dependent on their residuum contents in each experimental series. The final moisture contents of the upgraded products are discussed in the next section.

6.1.3 Final Moisture Gain or Loss

The final moisture gain or loss of the upgraded products in a period of 72 or 96 hours are presented in Tables 10 to 13. These data are also shown in Figures 7 to 10 which relate the final moisture gain or loss with the initial moistures of the upgraded products. In each figure, two trend lines are observed for different residuum contents and the effect of residuum on final moisture gain or loss is illustrated.

Under the environmental conditions used in the moisture sorption test, an upgraded product of higher initial moisture content will release moisture; while the products of lower initial moisture content will pick up moisture from the environment. An upgraded product with 4 - 5% initial moisture will be stable with respect to moisture sorption and desorption. Preventing moisture sorption will eliminate the heat of wetting which accelerates the process of low temperature oxidation. Producing upgraded products which release moisture will ensure product stability at the expense of product quality. Thus, the development of a practical method for ensuring a product of 4 - 5% moisture content warrants a further investigation.

6.1.4 Effect of Processing Conditions on Moisture Sorption

The moisture sorption curves for the zero % moisture products produced at similar residuum contents (5.2 to 5.4%) from all the experimental series are compared in Figure 11. The moisture sorption curves of these products do not show significant differences in moisture sorption. The data appear to suggest that the stabilization options investigated in this research contract do not affect moisture sorption characteristics of the upgraded products.

6.2 Oxygen Sorption Test

Oxygen sorption at ambient temperature was used as another measure of stability in this research contract. Sorption of oxygen by coal, which has been

reported by various researchers to be virtually complete chemisorption (1, 2, 5), is recognized world wide as a means for assessing the relative propensity of coal samples towards autogenous heating. The CANMET oxygen sorption method, which uses pulverized samples prepared under inert atmosphere, has been extensively developed for coal samples of various ranks. The CANMET method determines the sorption of oxygen and the production of carbon monoxide and carbon dioxide after a 96 hour sorption period in a static system.

To accommodate the upgraded products with residuum coating on the surface, a modified version of the CANMET procedure was used in this research contract. A 1.5 kg of sample of a full size consist was used instead of a 50 gm pulverized sample normally used in the procedure. The upgraded samples were purged with nitrogen and sealed in double plastic bags before the sorption test. This practice was used to prevent samples from oxidizing between the period of sample production and the oxygen sorption test, as the elapsed time between production and analysis could not be absolutely controlled or guaranteed. It has been shown that the results of the modified sorption test performed on representative splits of a sample and analyzed at the same time demonstrated a high degree of reproducibility.

Despite all the precautions and method development in applying the oxygen sorption test to the upgraded products, the results from this research contract suggest that the oxygen sorption data are affected and complicated by a number of factors, which may be beyond the control of an experimental program. Marked fluctuations were observed on oxygen consumption and carbon oxides produced for samples prepared under similar conditions; and the relative ranking of product stability was far from obvious. Trend lines therefore, were developed based on limited data to assist the interpretation of the test results.

6.2.1 Oxygen Sorption Data

Oxygen sorption data obtained on the upgraded products from all the experimental series are provided in Tables 6 to 9 inclusive. There are two test series (original, A, and replicate, B,) in each of the four experimental series, and

four products (0%, 4%, 8% moisture and water cooled products) in each test series. The oxygen sorption data for each experimental series are plotted in Figures 12 to 15 to develop the oxygen trend lines. A summary of sample history, the elapsed time between sample production and the sorption test, the residuum content of the products, and the general trends observed for all the experimental work is presented in this section on page 21.

6.2.1.1 Effects of Sample History, Residuum Content, and Elapsed Time to Analysis

The effects of these variables on oxygen sorption are discussed collectively because it is not possible to assess the impact on an individual basis. The results of the base case, the steam heating case, and the case of steam heating and CO_2 cooling, indicate that samples from the original test series (A) and of lower residuum contents have higher oxygen sorption capacities than those from the replicate tests (B) of higher residuum levels. These observations suggest that fresh samples are more prone to oxidation and suggest that residuum coating has a positive effect in reducing the oxygen sorption potential of the upgraded products. The results from the CO_2 cooling series, however, showed an entirely opposite trend. The replicate samples (B) from a more aged feedstock and with higher residuum contents absorbed more oxygen than samples from the original test series (A) of a lower residuum content. These results cannot be explained by sample aging or the protective function of the residuum , but they seem to be related to the elapsed time between sample production and the sorption test. The elapsed time between the sorption test appears to have some effect on the amount of oxygen consumption.

6.2.1.2 Effect of Moisture Content

One common observation of the general trends of the oxygen sorption data in all experimental series is that products of higher moisture contents absorbed more oxygen in the sorption test. The higher moisture products generated in this research contract are "manufactured" products made by allowing a predetermined

SUMMARY OF OBSERVATIONS

Experimental Series	Test Series	Date of Production	Elapsed Time of Sorption Test (Days)	Product Residuum %	General Trends Observed		
					O_2 Sorption	CO Production	CO_2 Production
Base Case	Original A Replicate B	03/89 07/89	8-18 6-14	3.0-3.6 5.2-5.6	(1) Samples from original series & of low residuum content absorbed more O_2 (2) High moisture products absorbed more O_2	(1) Relationship between O_2 & CO not clearly shown (2) Higher CO from lower moisture products	(1) Higher O_2 consumptions give high CO_2 (2) Higher CO_2 production from higher moisture products
CO_2 Conditioning	Original A Replicate B	04/89 07/89	10-34 8-12	3.9-5.7 4.2-6.8	(1) Samples from replicate series & of high residuum content absorbed more O_2 (2) High moisture products absorbed more O_2	(1) Samples absorbed more O_2 give high CO production (2) Higher CO from lower moisture products	Rapid Desorption of CO_2 as elapsed time increased
Steam Heating	Original A Replicate B	05/89 07/89	13-27 20-28	4.1-4.5 5.3-5.9	(1) Samples from original series & of low residuum content absorbed more O_2 (2) High moisture products absorbed more O_2	(1) Samples absorbed more O_2 give high CO production (2) Higher CO from lower moisture products	(1) Higher O_2 consumptions give higher O_2 (2) Higher CO_2 production from higher moisture products
Steam Heating and CO_2 Conditioning	Original A Replicate B	05/89 07/89	13-17 26	3.6-3.9 5.2-5.6	(1) Samples from original series & of low residuum content absorbed more O_2 (2) High moisture products absorbed more O_2	(1) Samples absorbed more O_2 give high CO production (2) Higher CO from lower moisture products	Rapid Desorption of CO_2 as elaspsed time increased

amount of water to equilibrate with a bone-dry product. The characteristics of the water in these products may or may not be the same as those present in products dried to the equivalent moisture levels.

The higher oxygen consumption observed for products of higher moistures appears to be caused by carbon-water reaction mechanisms which increase oxygen uptake. These chemical mechanisms have been reported by Berkowitz (1) and they lead to the production of hydroperoxides and carboxylic functions as follows:

$$\underline{C} + H_2O \rightarrow C(H)(OH)$$

$$C(H) + O_2 \rightarrow C\text{-}O\text{-}OH \text{ (hydroperoxides)}$$

$$2C(OH) + O_2 \rightarrow 2\text{-}C(=O)(OH) \text{ (carboxylic functions)}$$

where $\underline{C}$ is the active sites available on coal surface.

These reactions are occurring in addition to the chemisorption of oxygen which leads to change in surface polarity and the production of carbon monoxide via peroxide formation:

$$-C{=}C- + O_2 \rightarrow -C(=O){-}C(=O)- \rightarrow -C(=O) + C-$$

The general trends observed for the effect of moisture content are confirmed in the replicate test series (B) under steam heating and CO_2 cooling, when all the product samples of similar residuum contents were analysed for oxygen sorption in the same elapsed time (Table 9, replicate series B). The oxygen uptakes were 36, 31, 37 and 60 ml/100gm of sample for products of 0.5%, 1.1%, 3.0% and 5.3% moisture, respectively. These data indicate that total oxygen consumption appears to consist of chemisorption of oxygen together with oxygen reactions with species generated from reactions between carbon and moisture, which produce hydroperoxides and carboxylic functions.

6.2.1.3 General Comments on Oxygen Sorption Data

The results of this study revealed that oxygen sorption by upgraded products appears to be dependent on sample aging, the residuum content on the product, the moisture content of the products, and even the elapsed time between sample production and sorption analysis. A detailed study program is required to identify and quantify the effects of all these factors individually.

While the effects from sample aging, residuum level and moisture content can be reasonably understood or explained, it is difficult to find a satisfactory explanation for the effect of elapsed time. The decrease in oxygen sorption at longer elapsed time implies that there is air leakage in the sample bags which were purged with nitrogen and well sealed in the experimental procedures. A special series of experiments (Section 6.3) showed that sample storage procedures were not affecting stability results.

It should be pointed out that the discussion given above is an interpretation of the general trends observed in this research contract, and certain assumptions are used to assist the interpretation. However, the results of this study raise doubts of using oxygen sorption as the sole criterion for product stability for upgraded samples of varying moisture contents.

6.2.2 Carbon Monoxide Production Data

The carbon monoxide production results obtained in this research contract are shown in Tables 6 to 9 and their trend lines are presented in Figures 16 to 19. The table on page 21 in Section 6.2.1 summarizing the observations is also used to facilitate result discussion. Carbon monoxide production has been considered as a more meaningful factor than oxygen sorption data (2) because it is a direct measure of the oxidation products at ambient temperature.

Only small quantities of carbon monoxide are observed in the static oxygen sorption test. This is because carbon monoxide is a product of peroxides decomposition which only proceeds to a significant extent at temperatures above 70°C (5). These peroxides are formed from chemisorption of oxygen which also

changes the polarity of the coal surface. The production of carbon monoxide is also affected by the formation of hydroperoxides and carboxylic functions from the carbon-water reaction mechanisms.

6.2.2.1 Relationship Between Oxygen Sorption and CO Production

The general trend observed is that CO production is proportional to oxygen consumption. This trend is shown in the steam heating case, the case of using steam followed by CO_2 cooling, and the case of CO_2 cooling. The trend of higher oxygen consumption and higher CO production, however, was not clearly shown in the base case.

6.2.2.2 Effect of Moisture Content

Carbon monoxide production in all the experimental series showed one common trend: lower carbon monoxide production is observed for products of higher moisture contents. These data appear to support the chemical reactions between carbon and moisture which give a total reduction of carbon monoxide. These results also suggest that carbon monoxide appears to be a better evaluation criterion than oxygen sorption, because products of higher moisture contents should be more stable since they prevent moisture sorption which accelerates the low temperature oxidation process.

6.2.3 Carbon Dioxide Production Data

The carbon dioxide production results obtained from the upgraded samples are shown in Tables 6 to 9, and the trend lines are presented in Figure 20 to 23. Since carbon dioxide was used as a stabilization option in this research contract, the experimental series involving the addition of CO_2 (CO_2 cooling and steam heating followed by CO_2 cooling) are excluded from the discussion of the general trend lines. They are, however, described in this section as these results may provide some insight into sorption and desorption of CO_2 by the upgraded products.

It is generally believed that CO_2 is a product of oxidation. Experiments conducted using isotope oxygen (2) showed that about 50% of the CO_2 produced contained labelled oxygen. However, it should be noted that CO_2 can also be produced from the desorption of carbon dioxide from coal pores, from decarboxylation during the thermal treatment process, or from the decomposition of carboxylic functions produced from the carbon-water reactions. It is not possible to break down the total CO_2 production occurring in the experiments of this project.

6.2.3.1 Relationship Between Oxygen Sorption and CO2 Production

The general trend observed in the base case and the steam heating case is that higher oxygen consumption gives higher production of CO_2. This is demonstrated in Figures 20 and 21. This trend appears to suggest that CO_2 is produced in the oxidation process via the formation of peroxides and from the decomposition or carboxylic functions generated from carbon-water reactions.

6.2.3.2 Effect of Moisture Content

The general trend of CO_2 production when related to the moisture contents of the upgraded products is that higher CO_2 production is observed for higher moisture products. This trend is opposite to the CO production trend which shows higher CO production for lower moisture products. The trends appear to support the carbon-water reaction mechanisms which tend to produce more CO_2 at higher moisture levels via the decomposition of the carboxylic functions.

6.2.3.3 Trends of CO_2 in Experimental Series Utilizing CO_2 Stabilization

The CO_2 trends in the experimental series utilizing CO_2 stabilization are shown in Figures 22 and 23 for the cases of CO_2 cooling and steam heating followed by CO_2 cooling. There are drastic decreases of CO_2 at increased elapsed time between the experimental run and the sorption test. CO_2 desorption from the products which had been treated by CO_2 cooling was obvious.

While it was not possible to quantify the amount of CO_2 absorbed by the products during product treatment, the fact that desorption readily occurred and that similar oxygen sorptions were observed for products from all the experimental series suggest that only a small amount of CO_2 was absorbed by the upgraded products and that the CO_2 absorbed by the upgraded products can be easily replaced by oxygen. These observations do not support that CO_2 is preferentially absorbed by coal samples (3).

6.3 Special Experiments

A special series of experiments was performed to investigate the method of sample storage, as the elapsed time between sample production and the oxygen sorption test appeared to have some effect on oxygen sorption and carbon monoxide and carbon dioxide production. A sample was heated to 350°C in the heating drum and then cooled in carbon dioxide. Residuum was not added. The sample was split into 8 subsamples. Four samples were exposed to air and four samples were sealed in double plastic bags in the same manner as in the main experimental series. These samples were subjected to the oxygen sorption tests at different elapsed times. The results of this study are shown in Table 15 and presented in Figures 24 to 26.

The samples exposed to air show a drastic reduction in oxygen sorption and carbon monoxide and carbon dioxide production. The samples stored in double plastic bags are fairly constant in oxygen consumption and carbon monoxide and carbon dioxide production. The results of this special series confirm that the storage method used in this research contract is adequate for preventing oxidation of the samples.

The variations of oxygen sorption and carbon monoxide and carbon dioxide production observed in the main experimental series at different elapsed times, therefore, are not likely caused by oxidation from air leakage into the plastic bags. It would appear that other time dependent stabilizing mechanisms were occurring during the storage of upgraded samples generated from the experiment series utilizing stabilization options.

7.0 RELATIVE STABILITY OF PRODUCTS

As stated previously, moisture content, residuum content, and elapsed time between sample production and oxygen sorption testing all seem to affect stability. This section attempts to analyse the test results with one or more of these variables eliminated.

7.1 Product Stability at Equivalent Moisture Contents

Figures 27 to 34 present bar charts of oxygen sorption (Figures 27, 29, 31, 33) and carbon monoxide production (Figures 28, 30, 32, 34) for each test series at constant product moisture content (0, 4, 8, water cooled). The original test series (A) and replicates series (B) are presented. The bar charts indicate that reproducibility was inconsistent.

Considering only the A series tests, the bar charts indicate that, on average, CO_2 cooling is the best stabilization treatment and the steam heating is about equal to CO_2 cooling. However, steam heating followed by CO_2 cooling is definitely inferior to either of the individual stabilization methods. This effect of the combined methods is not consistent, but it occurs for every test series (i.e. in every Figure the steam plus CO_2 cooling bar for series A tests is higher than both the CO_2 cooling bar and the steam heating bar).

The opposite trend is evident for series B tests. Steam plus CO_2 cooling gives the best results (lowest bars) followed by steam heating, base case and then CO_2 cooling.

The fact that the A series tests results contradict the B series results makes it difficult to draw definitive conclusions. Overall, there does appear to be a benefit attributable to the stabilization methods since in one series CO_2 cooling gave the best results and in the other series steam heating plus CO_2 cooling gave the best results.

7.2 Product Stability at Equivalent Moisture and Residuum Contents

Figures 35 to 38 are bar charts showing oxygen sorption and carbon monoxide production for each test series at constant moisture content and for approximately constant residuum content (5-6%). The charted data was selected on the basis of residuum content and consequently, some of the charted results are from the A series and some from the B series.

The bar charts indicate that steam heating plus CO_2 cooling gives the most stable products. Overall, the stabilization methods produce more stable products than the base case. These conclusions ignore the effect of elapsed time and it should be noted that on average the base case samples were analysed at a shorter elapsed time than the stabilized products.

8.0 CONCLUSIONS

All the upgraded products produced from Obed coal using the two stage Gulf beneficiation process have equilibrium moistures in the range of 5 to 7%. These compare favorably with the equilibrium moisture of 12% in the raw coal sample. The stability of the products was assessed by moisture sorption and a modified version of the CANMET oxygen sorption method. While the moisture sorption test provides a good indication of product stability, it was found that the oxygen sorption data appear to be affected by various factors and complicated by the presence of moisture. These complications made the interpretation of the oxygen sorption data extremely difficult. Consequently, the ranking of product stability based on oxygen sorption is far from obvious. The results gathered from this study, however, are important in the development of low rank coal upgrading. The following specific conclusions can be made from the results of this research contract.

1. Higher residuum content reduces product equilibrium moisture.

2. Residuum content has a large impact on the initial moisture contents of the water cooled products. Higher residuum content gives products of lower initial moistures. For the bone dry products from the same test series, upgraded products of lower residuum content absorb more water in the moisture sorption test.

3. The moisture sorption test at 75% R.H. and 21°C provides a good indication of water sorption by products of various initial moisture levels. Under the conditions used in this test, a product of 4-5% moisture level will be stable with respect to moisture sorption and desorption in a 75% R.H. atmosphere. Higher moisture products will release moisture and lower moisture products will absorb moisture. Moisture sorption will make the products less stable towards autogenous heating.

4. A 4-5% moisture product will be stable with respect to moisture sorption and desorption. The actual production of a product of these moisture

contents using the water cooling method depends on the residuum contents of the products.

5. Processing options studied in this research contract do not seem to have any impact on moisture sorption behavior of the ugpraded products.

6. The application of the modified oxygen sorption method developed by CANMET to the upgraded products appears to be affected by sample history, the residuum contents on the products, and the elapsed time between sample production and analysis. The effects of these factors cannot be quantified from this program. The method used for sample storage before the oxygen sorption test was proven to be adequate in preventing sample oxidation.

7. Upgraded products of higher residuum content consume less oxygen in the oxygen sorption test.

8. Oxygen sorption by upgraded products is affected by the moisture introduced to the samples. The water forced back into the coal pores may or may not be the same as water present in the coals when they are dried down to the equivalent moisture levels. Higher oxygen consumption is observed for products of higher moisture content in all the experimental series. These observations appear to be the consequences of carbon-water reactions which lead to higher oxygen uptake.

9. Higher oxygen consumption by the products gives higher carbon monoxide production. Carbon monoxide production increases as product moisture decreases. These observations appear to be supported by the carbon-water reaction mechanisms in which moisture reduces the production of carbon monoxide due to the production of hydroperoxides and carboxylic species.

10. Higher oxygen consumption by the products correlates with higher carbon dioxide production. Higher production of carbon dioxide is observed for products of higher moisture content. In the experimental series when CO_2 was used as a cooling (stabilizing) agent there was significant desorption of CO_2 during the oxygen sorption test.

11. There are limitations in applying the modified oxygen sorption method developed by CANMET in assessing the stability of products generated in this research contract. There appear to be benefits of using steam heating and/or CO_2 stabilizing but the effects of elapsed time between sample production and analysis need to be quantified before a definitive conclusion can be made.

9.0 RECOMMENDATIONS

Product stability improvement was partially demonstrated in this research contract. To firmly establish the benefits of incorporating stabilization options in future studies, the following are recommended.

1. The exact quantity of residuum on the upgraded products must be controlled for results comparison. The data collected to date indicate that residuum impacts on product equilibrium moisture, initial moisture content of the water cooled products, moisture sorption and oxygen sorption.

2. The limitations of the modified CANMET oxygen sorption method need to be established. Oxygen sorption dependence on elapsed time between sample production and analysis should be investigated in detail. The trends from the experimental series utilizing stabilization options are not consistent with those observed in the base case.

3. The stability results indicate that oxygen absorption occurs in the presence of high carbon dioxide concentrations. The competitive absorption of oxygen and carbon dioxide should be evaluated.

4. Development of a practical method of introducing a known amount of water back to the upgraded products is required. Adjusting the moisture content of the upgraded products shows potential in product stabilization.

5. Additional methods for assessing product stability towards low temperature oxidation should be critically evaluated. These methods should be developed for further evaluation of upgraded products.

10.0 REFERENCES

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TABLE 1

SIZE ANALYSIS OF OBED COAL SAMPLE

Size Fraction (mm)	Weight (%)	Cumulative Weight (%)
+12.50	10.3	10.3
12.50 x 6.70	33.4	43.7
6.70 x 3.35	26.6	70.3
3.35 x 1.70	17.4	87.7
1.70 x 0.60	8.4	96.1
0.60 x 0.30	1.6	97.7
0.30 x 0.15	1.2	98.9
-0.15	1.1	100.0

TABLE 2
CHARACTERIZATION OF OBED COAL SAMPLE

Obed: High Volatile C Bituminous

Total Moisture	:	15.1%
Equilibrium Moisture	:	12.3%
Calorific Value, cal/g d.b.	:	6215
Proximate Analysis, d.b.		
Ash	:	15.8%
Volatile Matter	:	37.8%
Fixed Carbon	:	46.4%
Ultimate Analysis, d.b.		
Ash	:	15.8%
Carbon	:	60.3%
Hydrogen	:	4.6%
Nitrogen	:	1.6%
Sulfur	:	0.1%
Oxygen	:	17.6%

TABLE 3

ANALYSIS OF CENEX RESIDUUM USED FOR COAL BENEFICIATION

Chemical Analysis	Cenex PDA
H_2O%	0.0
Ash %	0.0
C%	83.8
H%	9.6
N%	0.7
S%	4.5
O% (By Difference)	1.4
H/C Mole Ratio	1.38
Calorific Value (Cal/gm)	9,820
Ni (ppm)	75.0
V (ppm)	200.0
Physical Properties	
Softening Pt (°C)	61
Penetration (at 25°C)	16
Density (g/ml at 15.6°C)	1.05
Viscosity (cps)	
at 150°C	577
at 200°C	77

TABLE 4

EXPERIMENTAL DESIGN AND EXPERIMENTAL SERIES

Beneficiation Experiments

Heating Medium	Combustion Gases		Steam and Combustion Gases	
Cooling Mechanism	Base Case	CO_2 Conditioning	Base Case	CO_2 Conditioning
	(Air cooled N_2 purged)		(Air Cooled N_2 purged)	
Products	0% moisture 4% moisture 8% moisture	0% moisture 4% moisture 8% moisture	0% moisture 4% moisture 8% moisture	0% Moisture 4% moisture 8% moisture
	Water cooled Product (N_2 purged)	Water cooled Product (CO_2 purged)	Water cooled Product (N_2 purged)	Water cooled Product (CO_2 purged)
	Series 1 (original and replicate)	Series 2 (original and replicate)	Series 3 (original and replicate)	Series 4 (original and replicate)

All samples in duplicate.
- Series 1 - 8 samples
- Series 2 - 8 samples
- Series 3 - 8 samples
- Series 4 - 8 samples

TABLE 5

OPERATING CONDITIONS FOR

COAL BENEFICIATION EXPERIMENTS

	Base Case		CO_2 Cooling		Steam Heating		Steam, CO_2 Cooling	
	Series A	Series B	Series A	Series B	Series A	Series B	Series A	Series B
Feed Rate (target) g/m	550	600	600	600	600	600	600	600
Steam Rate g/m	--	--	--	--	620	620	620	620
Residuum	Cenex	Cenex	Cenex	Cenex	Cenex	Cenex	Cenex	Cenex
Residuum Rate (target) g/m	16	20	20	20	20	20	20	20
Dry Product Rate (actual) g/m	440	404	452	417	380	382	446	398
Wet Product Rate (actual) g/m	--	332	600	453	443	400	405	390
Temperatures								
Hot coal exiting heating drum °C	360	355	345	350	350	350	345	350
Hot product exiting treating drum °C	185	165	175	170	175	170	190	165
Water cooled product exiting auger °C	26	25	30	30	33	--	27	--
Gas at heating drum exit °C	480	500	400	495	475	480	480	485

TABLE 6

RESULTS OF PRODUCT CHARACTERIZATION

AND OXYGEN SORPTION TEST

EXPERIMENTAL SERIES: BASE CASE

Sample #	Sample Ident.	Sample History (Date)			Product Characteristics			Oxygen Sorption Data		
		Product.	Sorption Test	Elapsed Time (days)	% H_2O	% Res	% Eq Moisture	O_2 ml/100gm	CO ppm	CO_2 ppm
1	0	23/2	6/3	11	0	3.6	6.2	79	1,092	752
2	4	23/2	13/3	18	3.3	3.0	6.4	113	368	3,720
3	8	23/2	13/3	18	6.7	3.2	6.1	183	401	4,933
4	H_2O	23/2	3/3	8	4.2	5.1	5.3	153	1,116	2,575
5	0	4/7	10/7	6	0	5.4	5.5	83	683	656
6	4	4/7	18/7	14	3.0	5.2	5.4	82	1,474	1,751
7	8	4/7	18/7	14	5.6	5.2	5.6	124	1,790	3,068
8	H_2O	4/7	10/7	6	1.9	5.6	4.9	130	962	1,359

TABLE 7
RESULTS OF PRODUCT CHARACTERIZATION AND OXYGEN SORPTION TEST

EXPERIMENTAL SERIES: CO_2 COOLING

Sample #	Sample Ident.	Sample History (Date)			Product Characteristics			Oxygen Sorption Data		
		Product.	Sorption Test	Elapsed Time (days)	% H_2O	% Res	% Eq Moisture	O_2 ml/100gm	CO ppm	CO_2 ppm
9	0	4/4	14/4	10	0.7	5.2	5.8	69	275	49,000
10	4	4/4	8/5	34	4.5	5.5	6.2	34	412	7,697
11	8	4/4	8/5	34	8.0	5.7	6.6	83	448	5,934
12	H_2O)	4/4	14/4	10	3.6	3.9	6.8	85	247	8,012
13	0	6/7	14/7	8	0.6	6.4	5.1	101	1,908	51,463
14	4	6/7	18/7	12	3.0	6.7	5.1	116	1,793	47,279
15	8	6/7	18/7	12	5.9	6.8	5.6	139	1,744	48,659
16	H_2O	6/7	14/7	8	2.5	4.2	7.9	99	1,025	20,944

TABLE 8

RESULTS OF PRODUCT CHARACTERIZATION

AND OXYGEN SORPTION TEST

EXPERIMENTAL SERIES: STEAM HEATING

Sample #	Sample Ident.	Sample History (Date)			Product Characteristics			Oxygen Sorption Data		
		Product.	Sorption Test	Elapsed Time (days)	% H_2O	% Res	% Eq Moisture	O_2 ml/100gm	CO ppm	CO_2 ppm
17	0	23/5	5/6	13	0	4.5	5.8	73	1,007	553
18	4	23/5	9/6	17	3.5	4.0	6.0	73	594	3,051
19	8	23/5	19/6	27	6.8	4.1	6.4	73	545	2,321
20	H_2O	23/5	5/6	13	3.0	4.5	6.7	89	769	1,850
21	0	11/7	31/7	20	0.4	5.4	6.2	42	861	482
22	4	11/7	8/8	28	3.2	5.9	6.2	43	502	1,178
23	8	11/7	8/8	28	5.8	5.3	6.4	88	587	2,008
24	H_2O	11/7	31/7	20	1.0	5.4	6.3	40	629	673

TABLE 9

RESULTS OF PRODUCT CHARACTERIZATION

AND OXYGEN SORPTION TEST

EXPERIMENTAL SERIES: STEAM HEATING AND CO_2 COOLING

Sample #	Sample Ident.	Sample History (Date)			Product Characteristics			Oxygen Sorption Data		
		Product.	Sorption Test	Elapsed Time (days)	% H_2O	% Res	% Eq Moisture	O_2 ml/100gm	CO ppm	CO_2 ppm
25	0	23/5	5/6	13	0	3.7	6.8	91	1,192	40,712
26	4	23/5	9/6	17	3.8	3.9	6.6	108	796	32,267
27	8	23/5	9/6	17	6.7	3.6	6.6	138	807	25,042
28	H_2O	23/5	5/6	13	3.0	3.8	6.3	114	927	6,818
29	0	13/7	8/8	26	0.5	5.2	6.0	36	682	5,079
30	4	13/7	8/8	26	3.0	5.4	6.5	37	437	8,057
31	8	13/7	8/8	26	5.3	5.3	6.4	60	530	7,452
32	H_2O	13/7	8/8	26	1.1	5.6	4.4	31	479	1,575

TABLE 10

MOISTURE SORPTION FOR OBED COAL PRODUCTS

BASE CASE (21°C AND 75% R.H.)

Sample #	Sample Ident.	Moisture Content at 0 Hour (%)	24 Hour (%)	48 Hour (%)	72 Hour (%)	96 Hour (%)	Final Weight Gain (loss) at 72 or 96 Hours (%)
Base Case A	0	0	2.77	3.61	3.98	--	3.98
	4	3.20	3.78	3.92	4.01	--	0.81
	8	6.25	5.40	5.30	5.30	--	-0.95
	H_2O	4.15	4.39	4.48	4.48	--	0.33
Base Case B	0	0	1.32	2.00	2.41	2.74	2.74
	4	3.50	3.79	3.88	3.93	3.93	0.43
	8	6.20	5.16	5.11	4.96	4.96	-1.24
	H_2O	2.06	2.62	2.82	3.02	3.04	0.98

TABLE 11

MOISTURE SORPTION FOR OBED COAL PRODUCTS

CO_2 COOLING (21°C AND 75% R.H.)

Sample #	Sample Ident.	Moisture Content at 0 Hour (%)	24 Hour (%)	48 Hour (%)	72 Hour (%)	96 Hour (%)	Final Weight Gain (loss) at 72 or 96 Hours (%)
CO_2 A	0	0.15	1.96	2.73	3.15	--	3.0
	4	3.55	3.84	3.98	4.03	--	0.48
	8	7.20	5.60	5.45	5.40	--	-1.8
	H_2O	3.50	4.31	4.55	4.69	--	1.19
CO_2 B	0	0.30	1.67	2.24	2.57	2.83	2.53
	4	3.10	3.49	3.63	3.73	3.73	0.63
	8	5.65	5.22	5.18	5.18	5.18	-0.47
	H_2O	2.25	3.04	3.46	3.72	3.96	1.7

TABLE 12

MOISTURE SORPTION FOR OBED COAL PRODUCTS

STEAM HEATING (21°C AND 75% R.H.)

Sample #	Sample Ident.	Moisture Content at 0 Hour (%)	24 Hour (%)	48 Hour (%)	72 Hour (%)	96 Hour (%)	Final Weight Gain (loss) at 72 or 96 Hours (%)
Steam A	0	0	2.73	4.05	4.23	--	4.23
	4	3.01	4.08	4.28	4.39	--	1.38
	8	6.15	5.49	5.39	5.39	--	-0.76
	H_2O	3.05	3.87	4.44	4.53	--	1.48
Steam B	0	0.1	1.38	2.11	2.63	3.01	2.91
	4	2.70	3.28	3.47	3.76	3.85	1.15
	8	6.05	5.81	5.77	5.77	5.77	-0.28
	H_2O	0.85	2.22	2.75	3.17	3.41	2.56

TABLE 13

MOISTURE SORPTION FOR OBED COAL PRODUCTS

STEAM HEATING AND CO_2 COOLING (21°C AND 75% R.H.)

Sample #	Sample Ident.	Moisture Content at 0 Hour (%)	24 Hour (%)	48 Hour (%)	72 Hour (%)	96 Hour (%)	Final Weight Gain (loss) at 72 or 96 Hours (%)
Steam/ CO_2 A	0	0	3.14	4.41	4.59	--	4.59
	4	3.80	4.79	4.99	5.03	--	1.23
	8	6.70	6.04	5.90	5.90	--	-0.8
	H_2O	3.30	4.18	4.40	4.49	--	1.19
Steam/ CO_2 B	0	0.10	1.28	1.96	2.49	2.82	2.72
	4	3.00	3.58	3.82	4.01	4.10	1.10
	8	5.30	5.21	5.21	5.21	5.21	-0.1
	H_2O	0.40	1.34	1.78	2.16	2.40	2.0

TABLE 14

INITIAL MOISTURE CONTENTS OF WATER COOLED PRODUCTS AT DIFFERENT RESIDUUM CONTENTS

Experiment Series		Moisture Contents	Residuum Level
Base Case	Test Set A	4.15	5.1
	Test Set B	2.06	5.6
CO_2 Cooling	Test Set A	3.50	3.9
	Test Set B	2.25	4.2
Steam Heating	Test Set A	3.05	4.5
	Test Set B	0.85	5.4
Steam Heating and CO_2 Cooling	Test Set A	3.30	3.8
	Test Set B	0.40	5.6

TABLE 15

SPECIAL EXPERIMENTS INVESTIGATING THE IMPACT OF SAMPLE STORAGE METHODS ON OXYGEN SORPTION TEST

Samples Exposed to Air

Sample	Elapsed Time Between Production and Oxygen Sorption Test (days)	O_2 Sorption (ml/100gm)	CO (ppm)	CO_2 (ppm)
1	5	195	3,282	38,591
2	11	108	2,727	3,311
3	25	73	2,027	1,676
4	28	56	1,810	1,217

Samples Purged with N_2 and Stored in Double Plastic Bags

1	5	193	3,230	41,034
2	11	182	3,061	39,827
3	25	164	2,919	42,504
4	28	162	2,832	41,082

FIGURE 1

TWO-STAGE PROCESS SCHEME

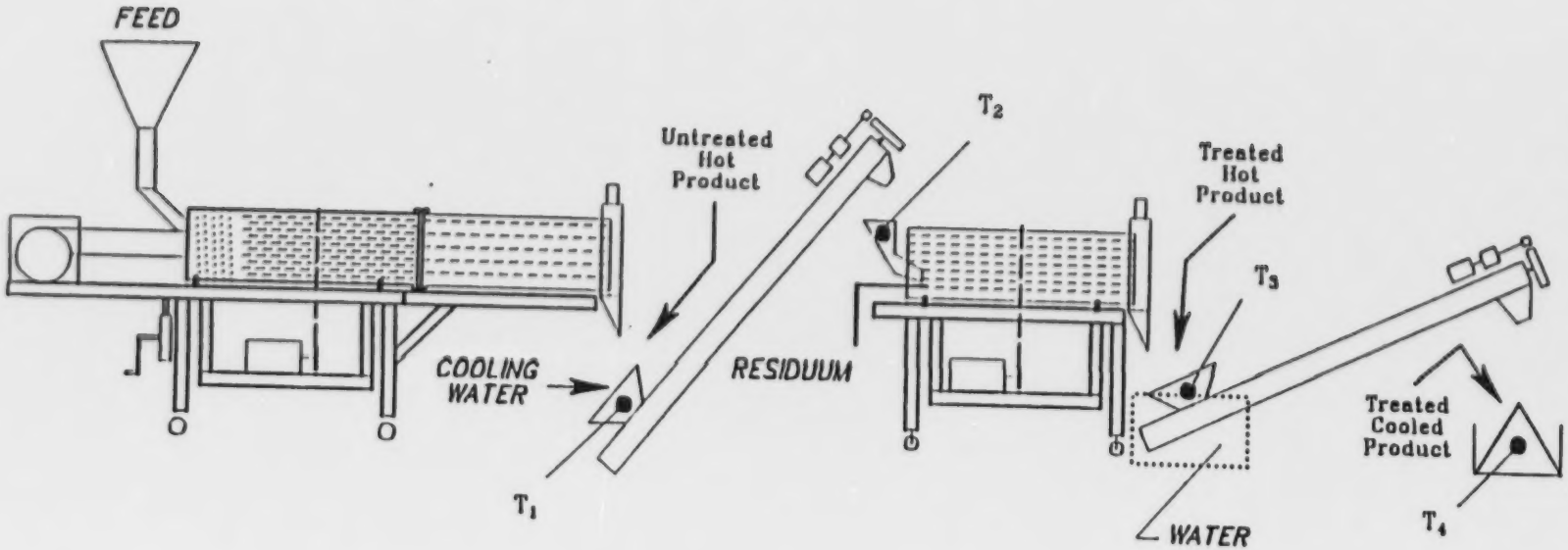


Figure 2
MOISTURE SORPTION CHRACTERISTICS OF UPGRADED PRODUCTS

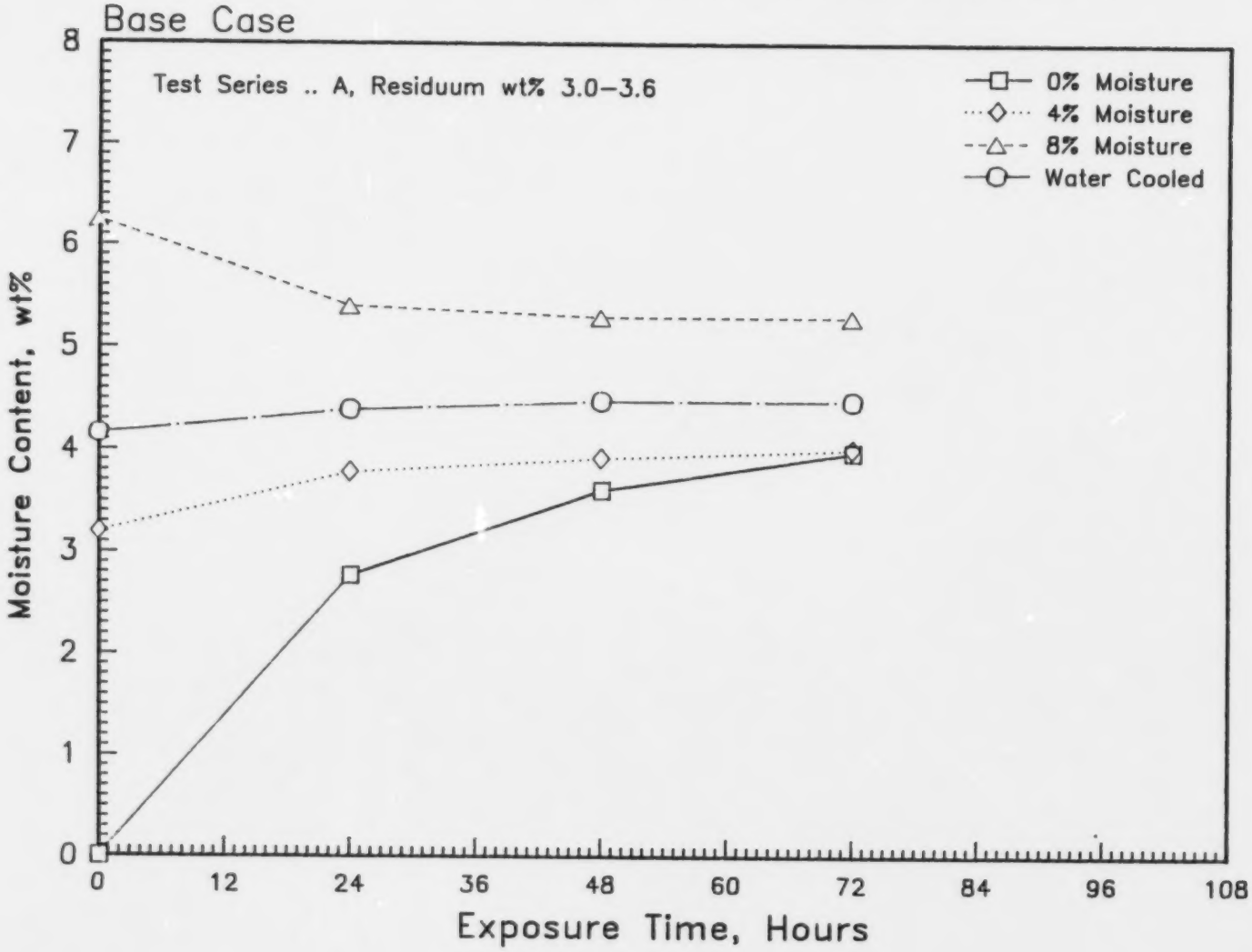


Figure 3
MOISTURE SORPTION CHRACTERISTICS OF UPGRADED PRODUCTS

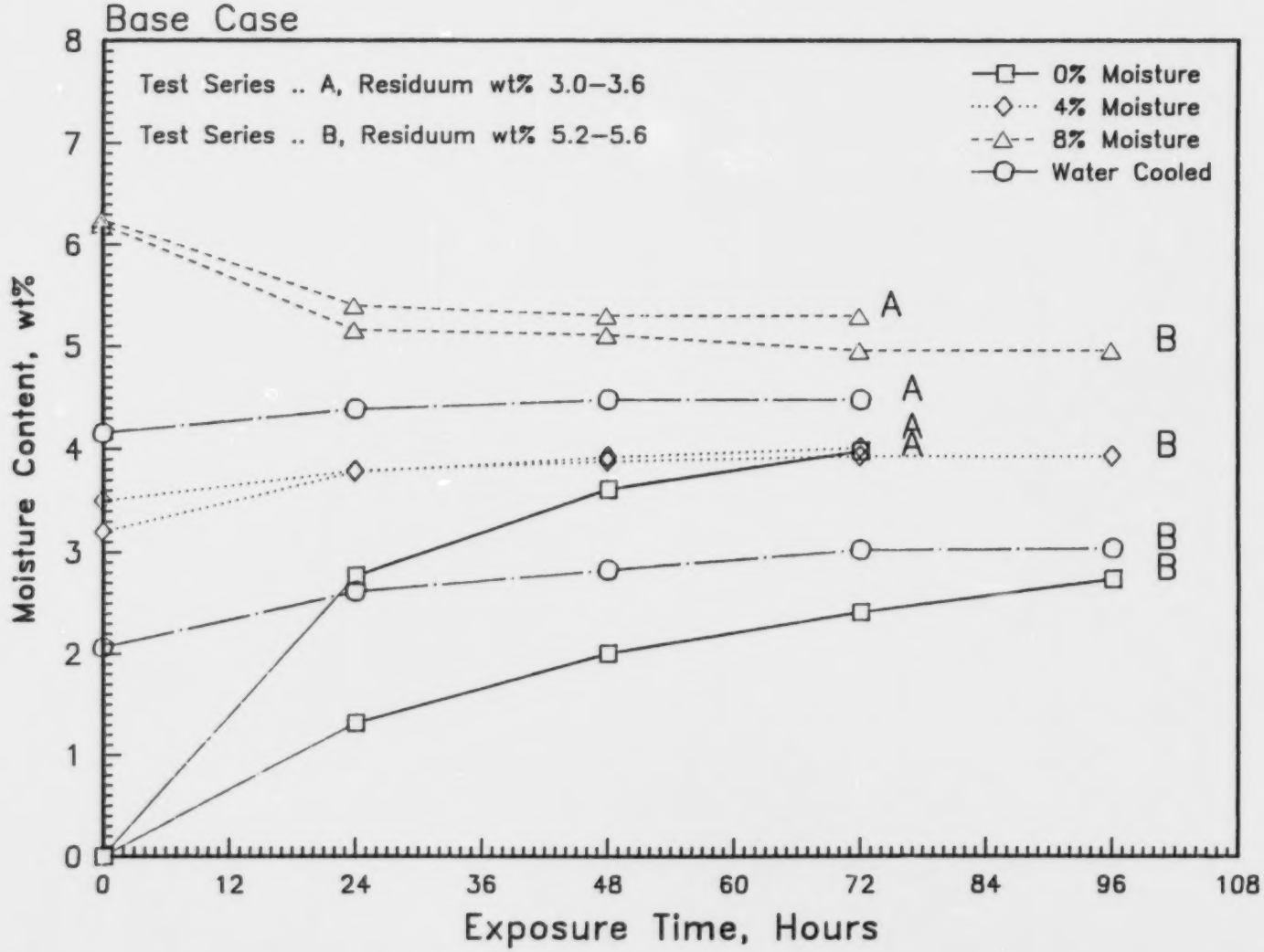


Figure 4

MOISTURE SORPTION CHRACTERISTICS OF UPGRADED PRODUCTS

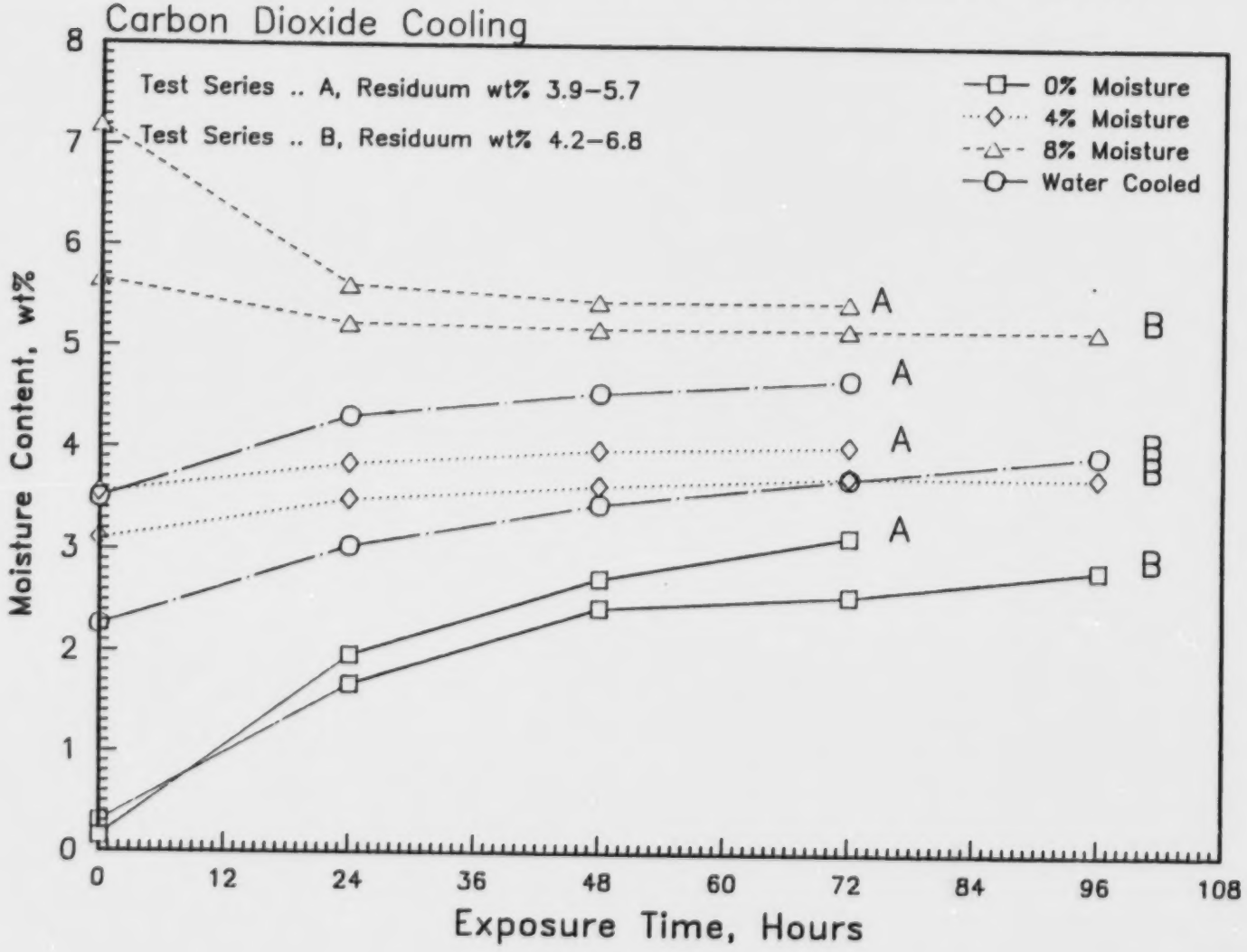


Figure 5
MOISTURE SORPTION CHRACTERISTICS OF UPGRADED PRODUCTS

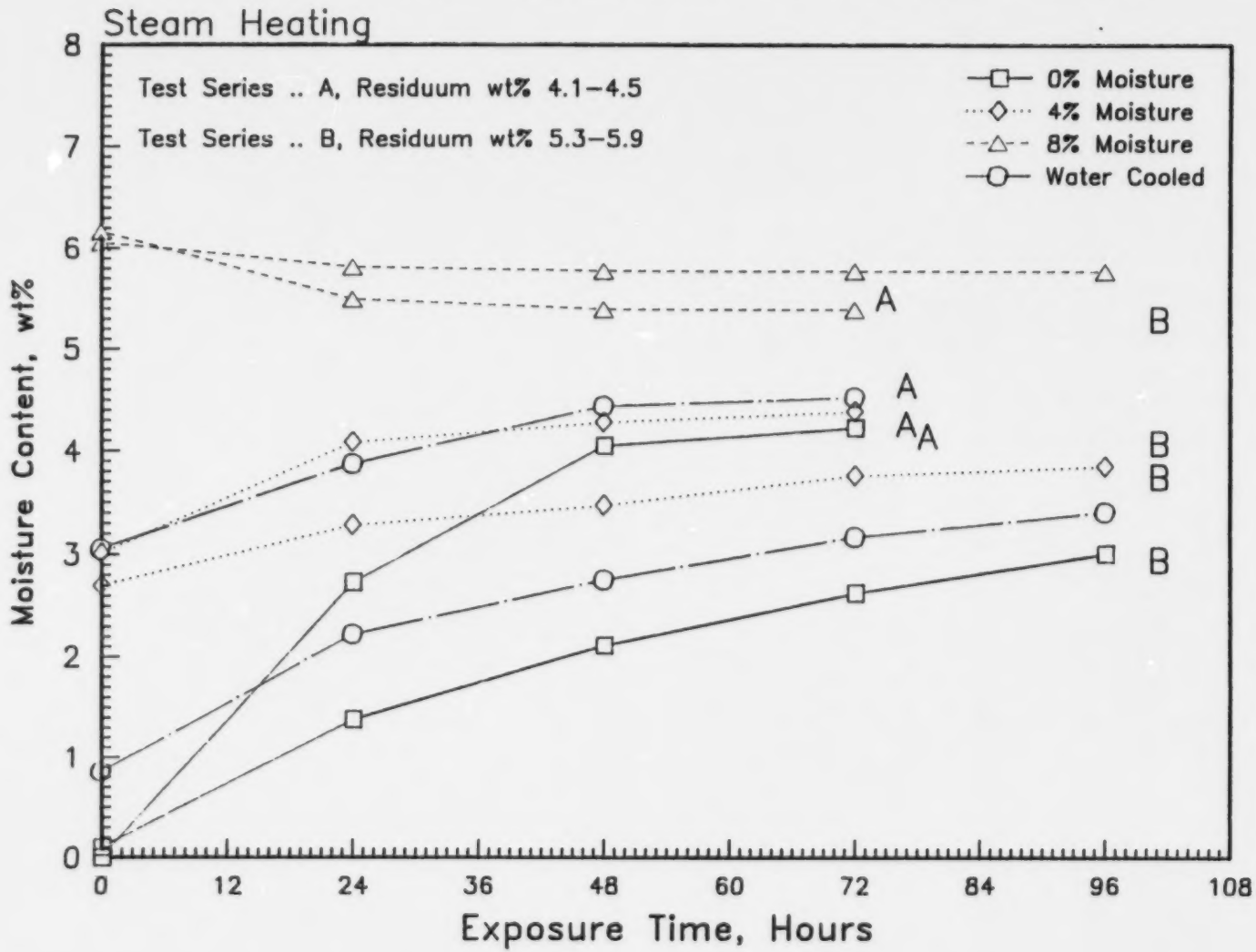


Figure 6

MOISTURE SORPTION CHRACTERISTICS OF UPGRADED PRODUCTS

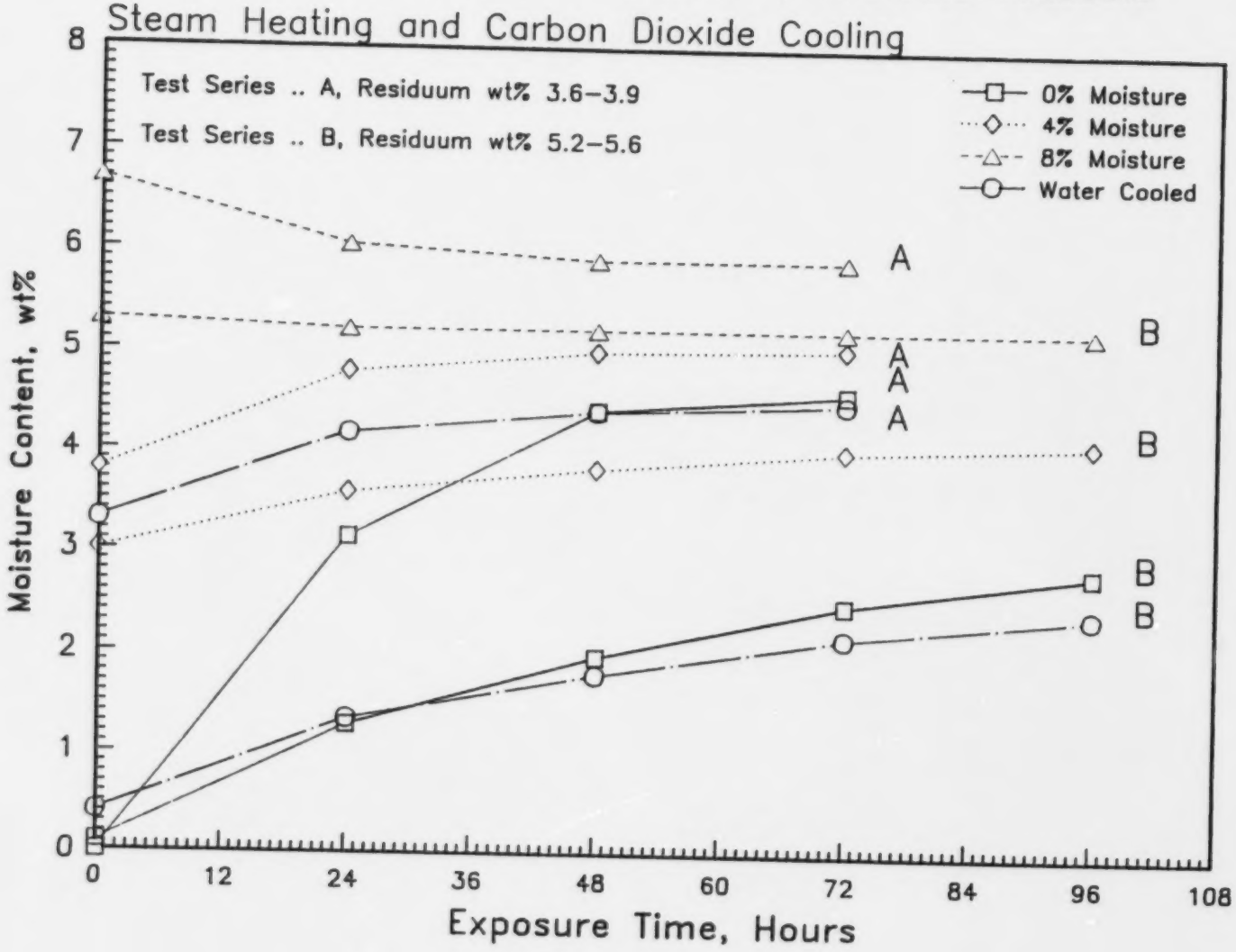


Figure 7
MOISTURE SORPTION CHRACTERISTICS OF UPGRADED PRODUCTS

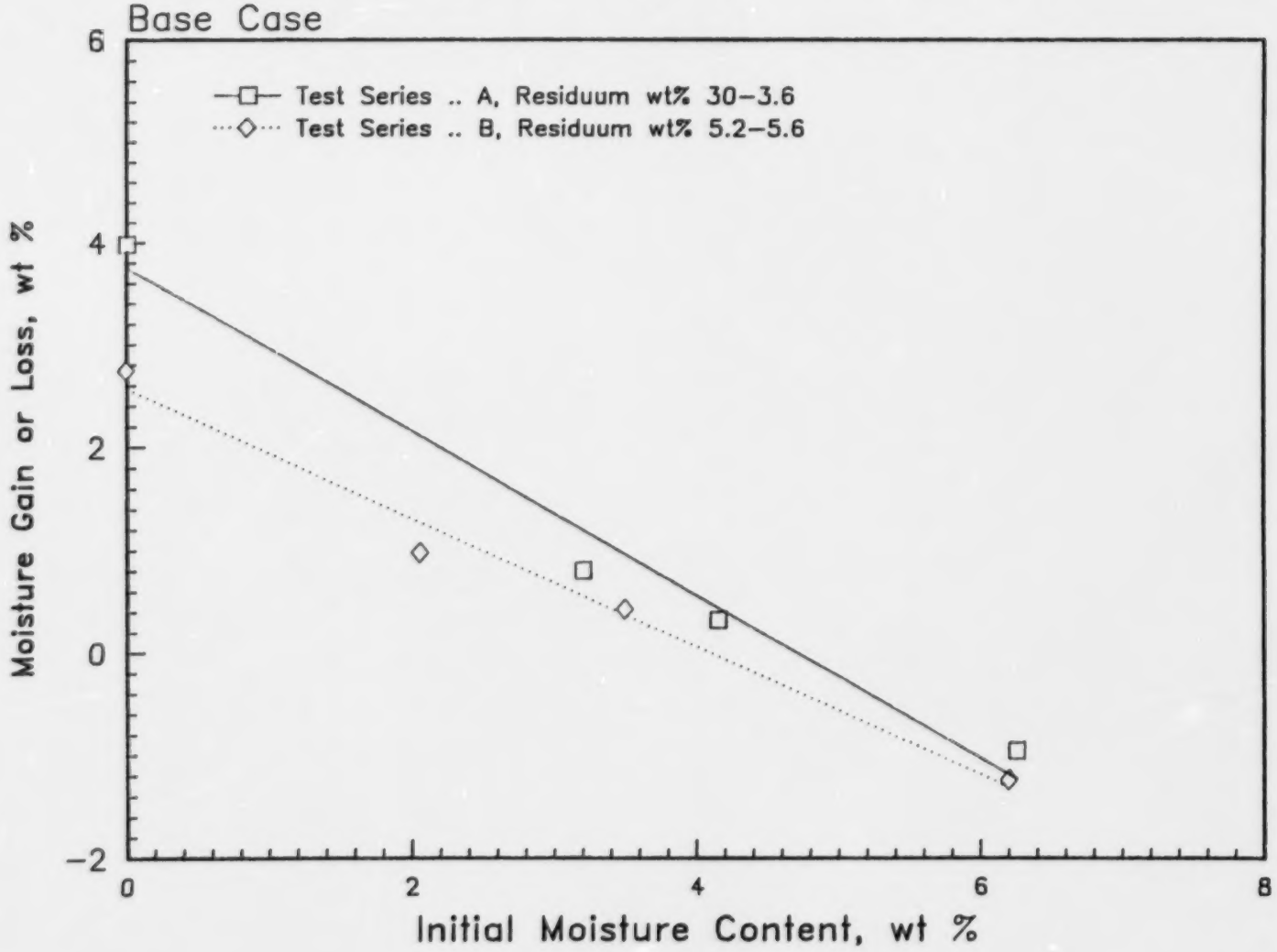


Figure 8

MOISTURE SORPTION CHRACTERISTICS OF UPGRADED PRODUCTS

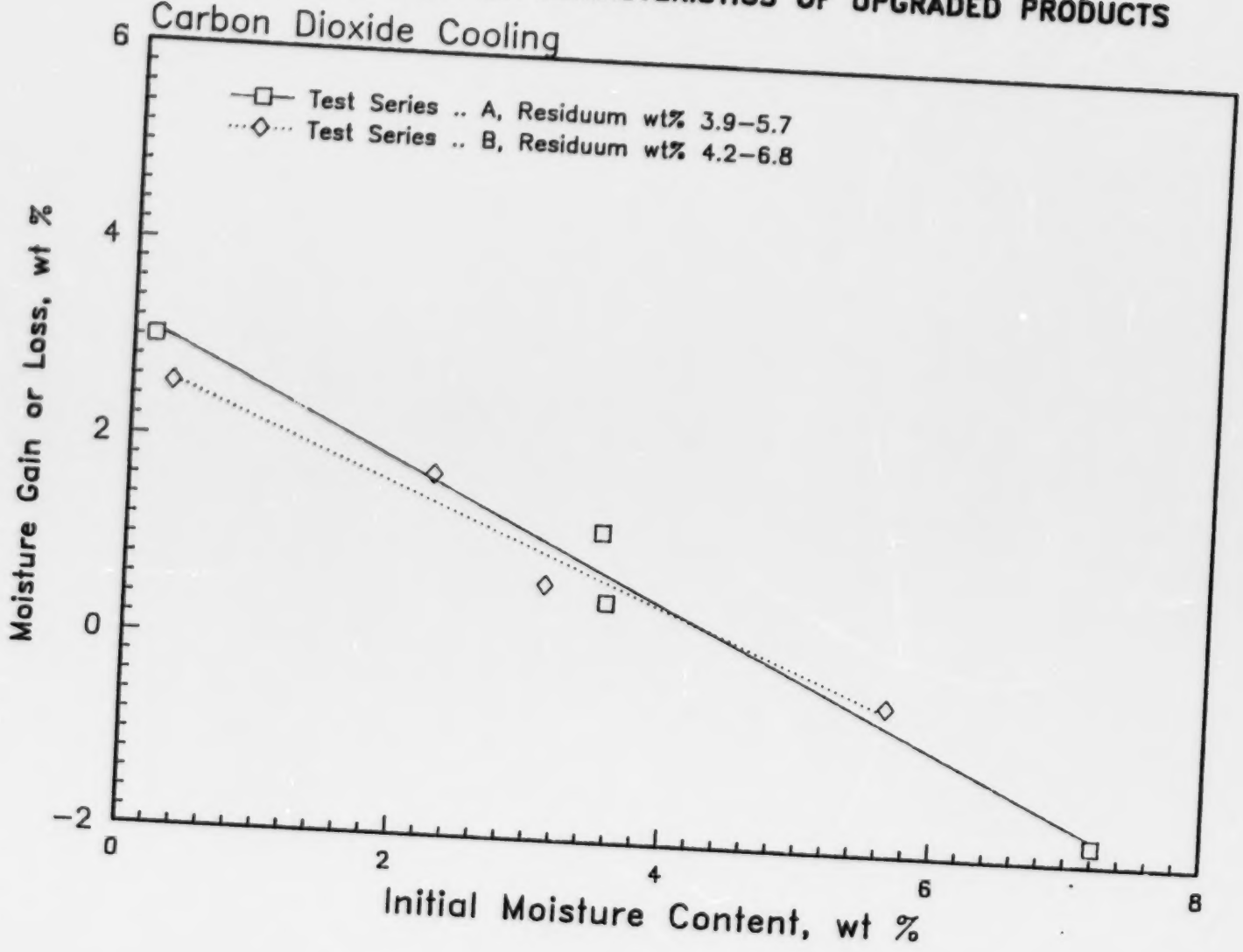


Figure 9
MOISTURE SORPTION CHRACTERISTICS OF UPGRADED PRODUCTS

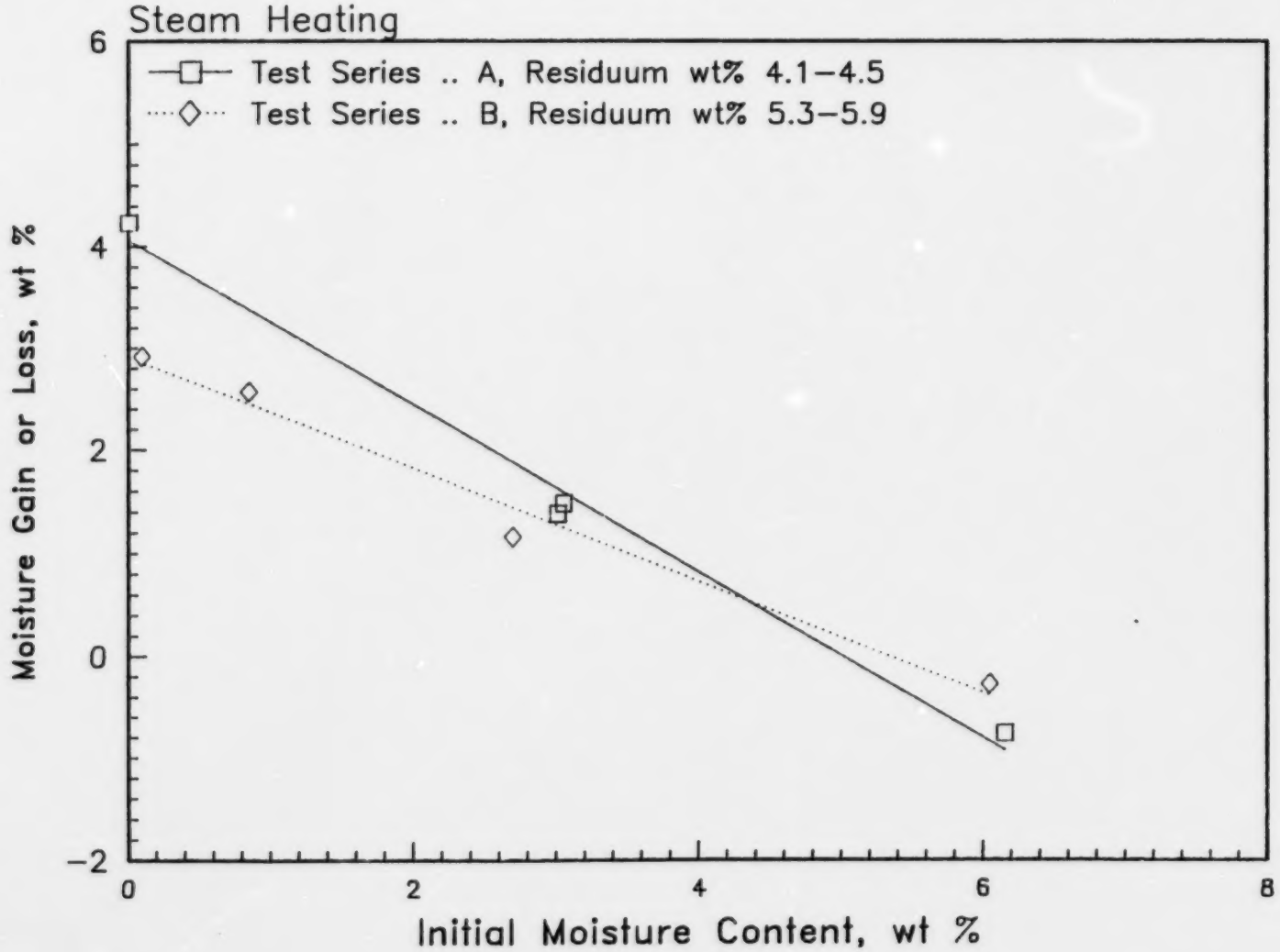


Figure 10
MOISTURE SORPTION CHRACTERISTICS OF UPGRADED PRODUCTS

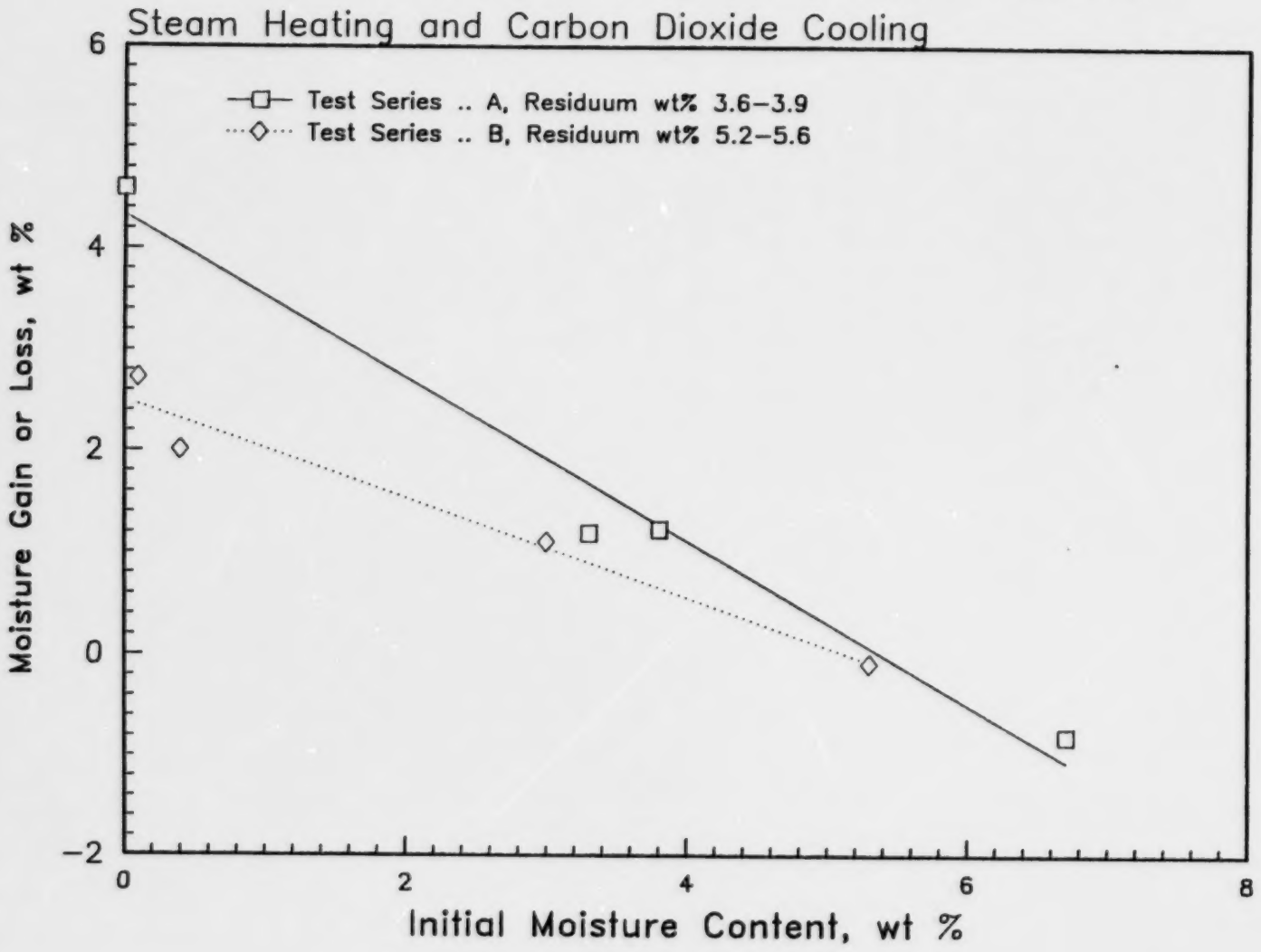


Figure 11
EFFECT OF PROCESSING CONDITIONS ON MOISTURE SORPTION RATE

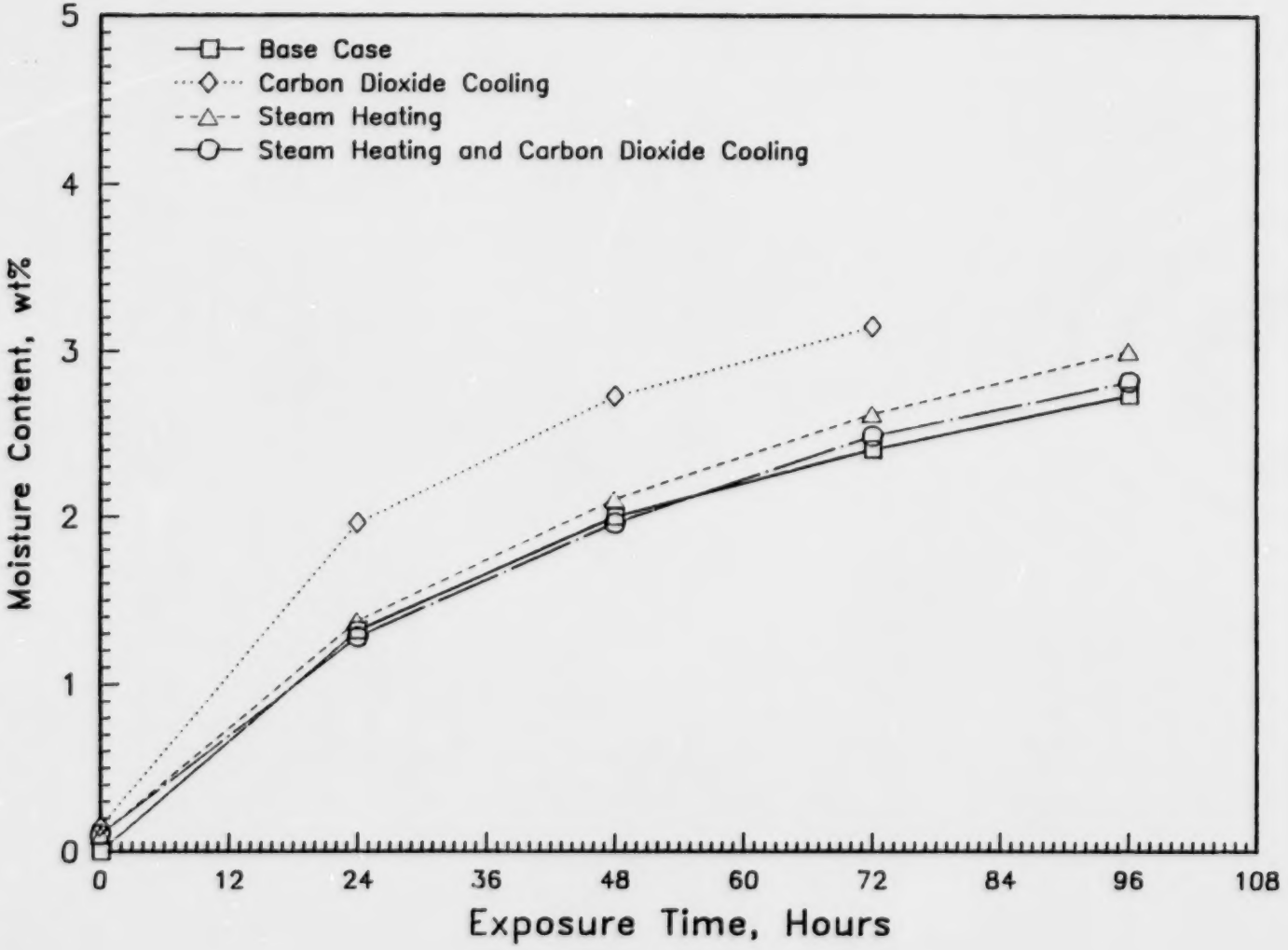


Figure 12
OXYGEN SORPTION FOR OBED COAL PRODUCTS

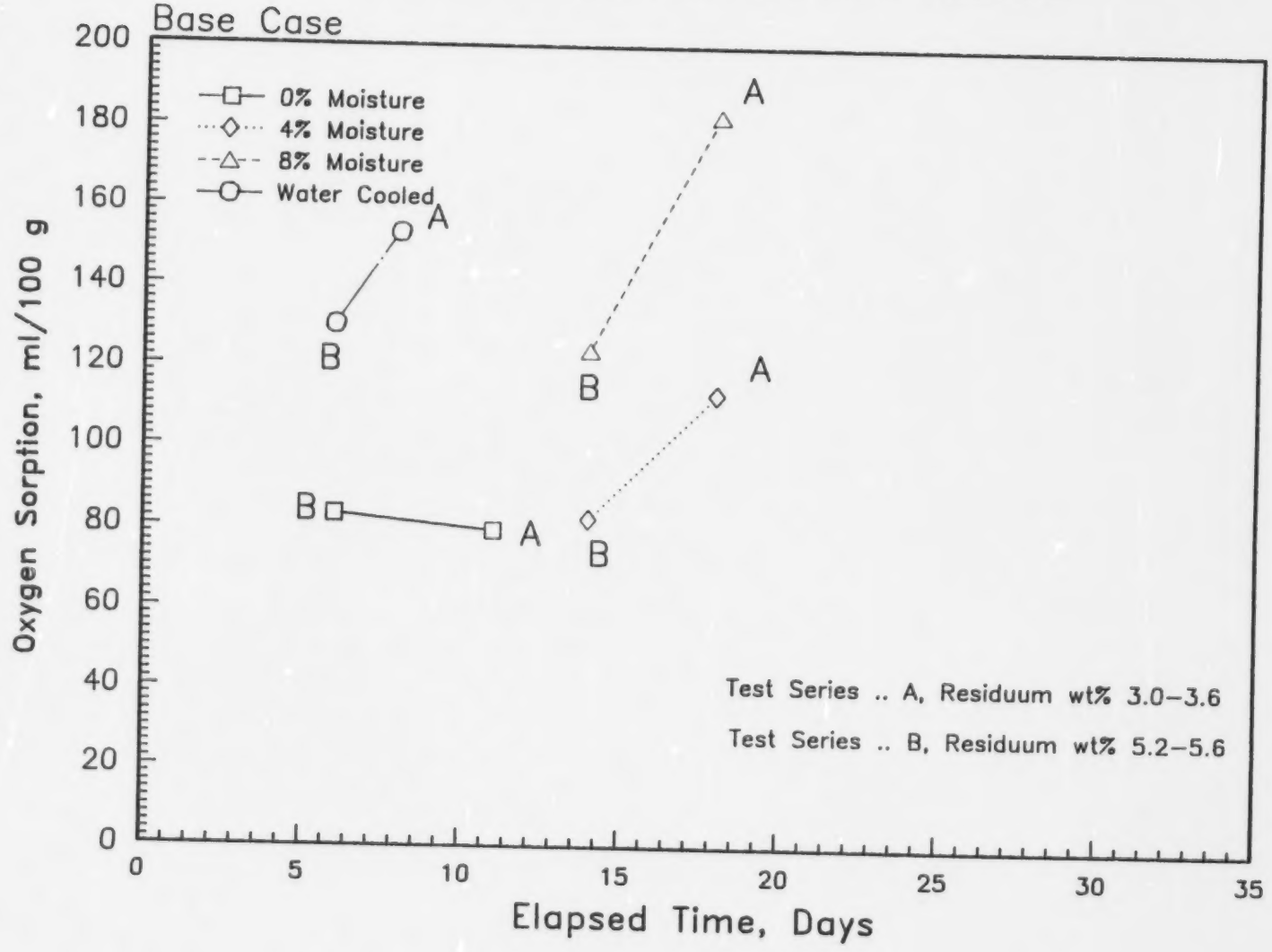


Figure 13
OXYGEN SORPTION FOR OBED COAL PRODUCTS

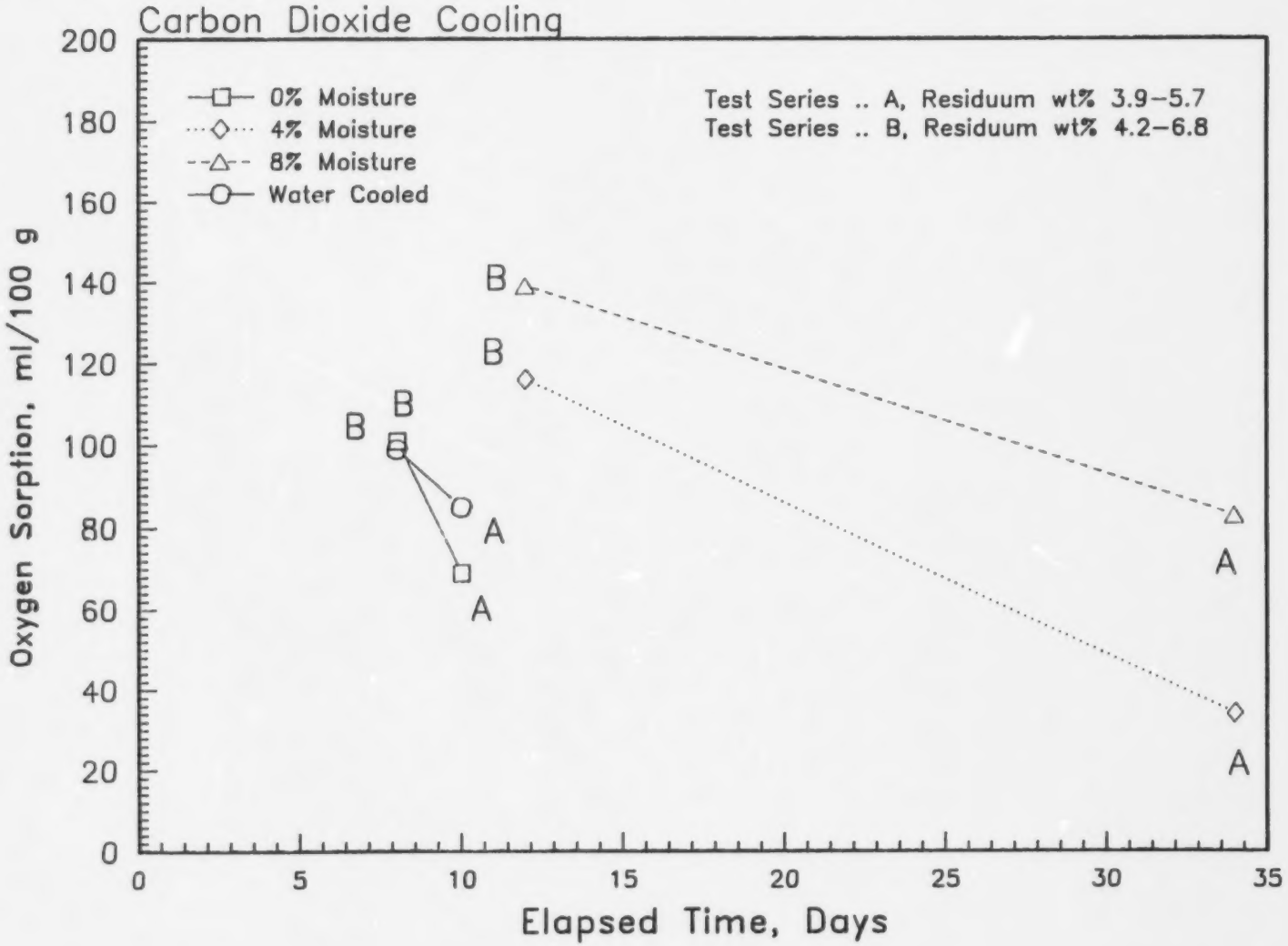


Figure 14
OXYGEN SORPTION FOR OBED COAL PRODUCTS

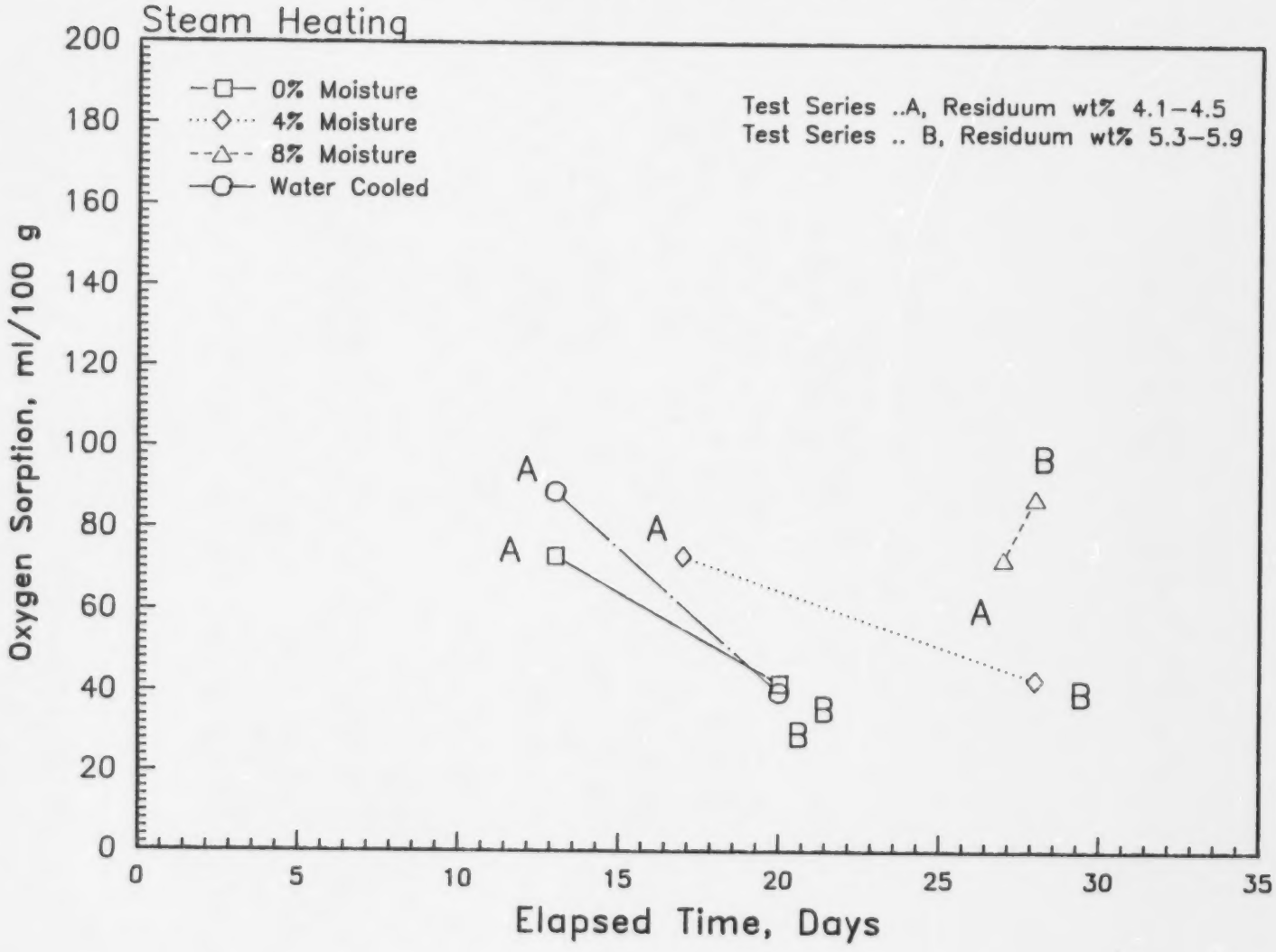


Figure 15
OXYGEN SORPTION FOR OBED COAL PRODUCTS

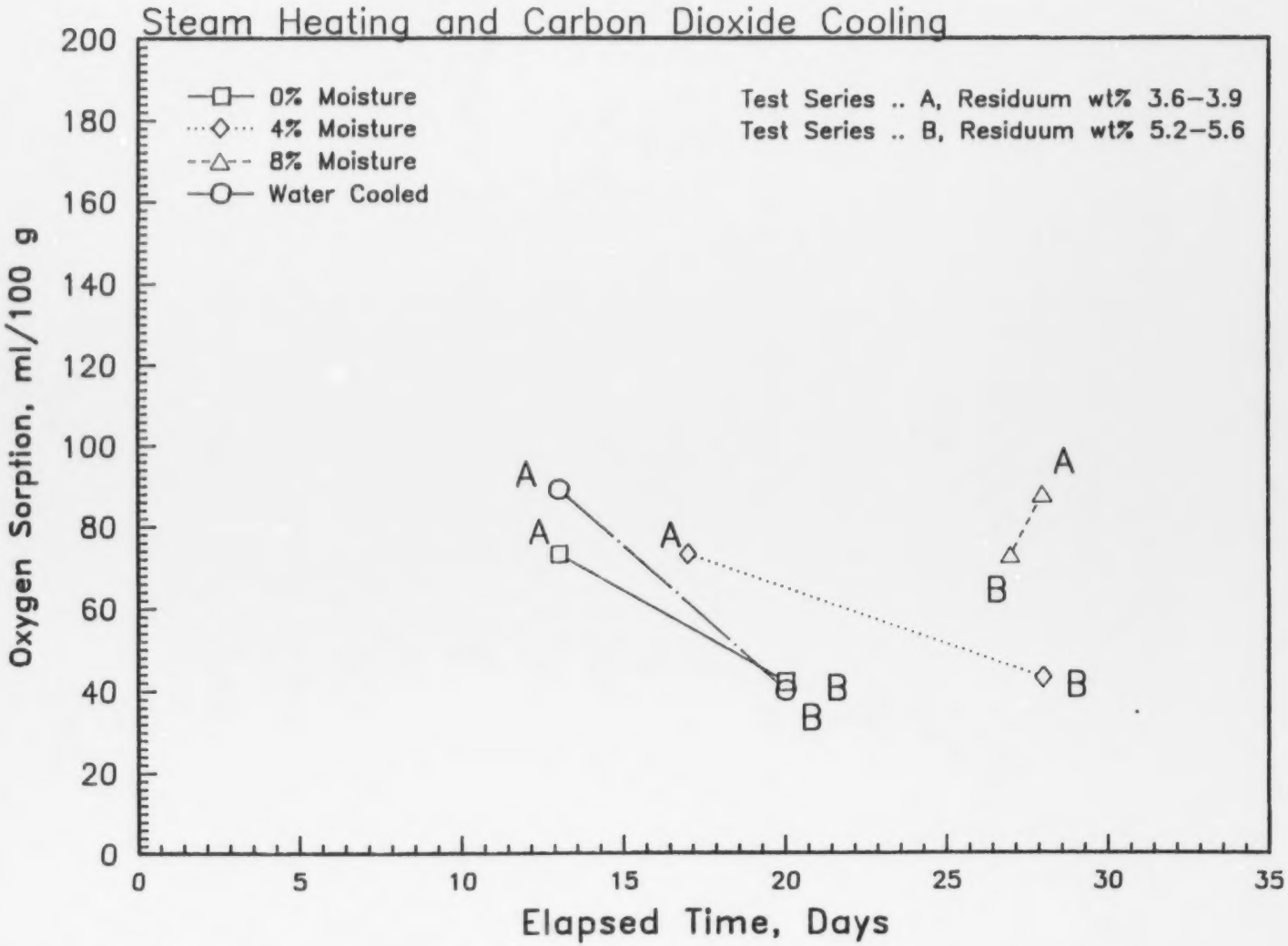


Figure 16
ANALYSIS OF HEAD GASES FOR OXYGEN SORPTION TEST

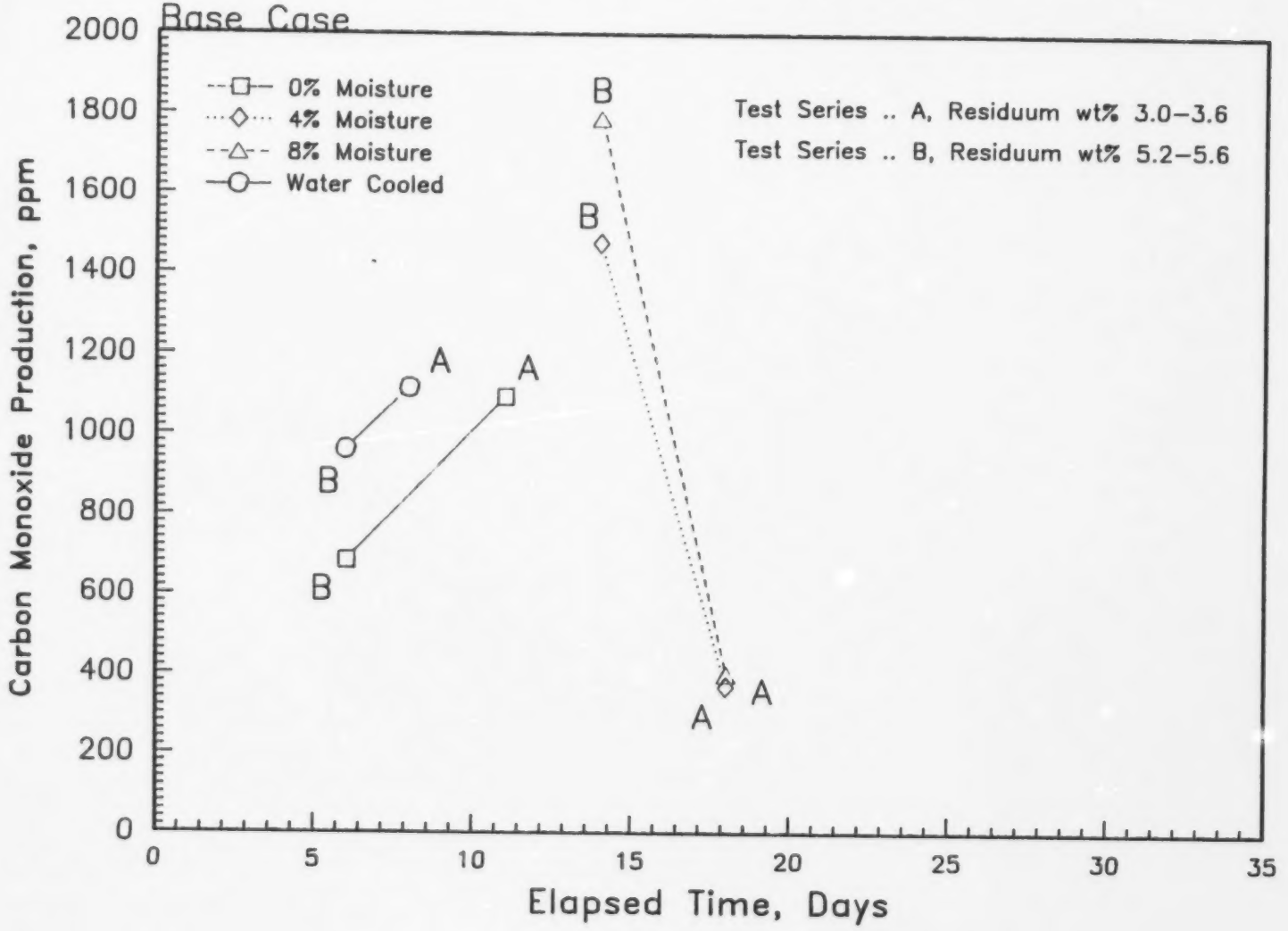


Figure 17
ANALYSIS OF HEAD GASES FOR OXYGEN SORPTION TEST

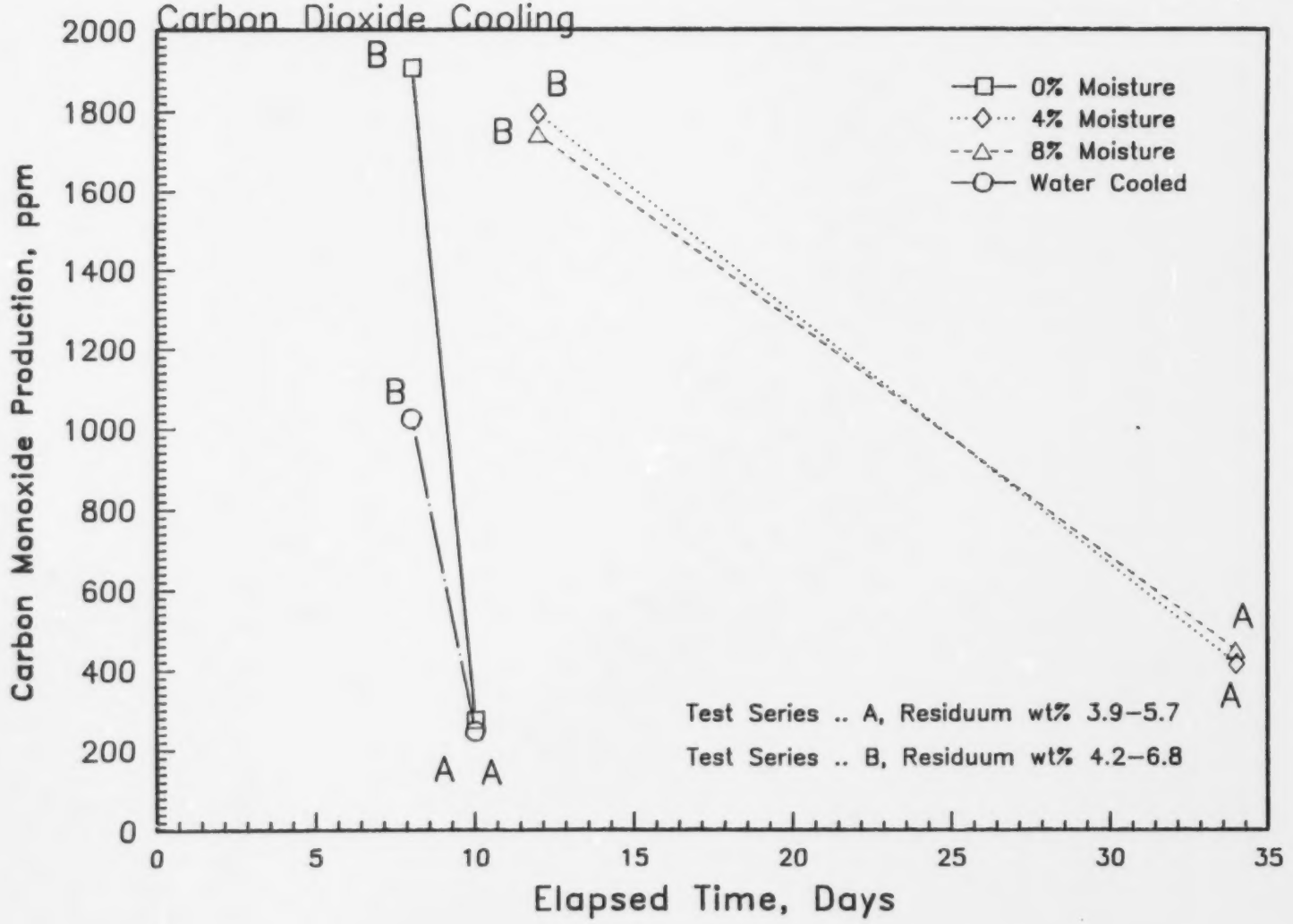


Figure 18
ANALYSIS OF HEAD GASES FOR OXYGEN SORPTION TEST

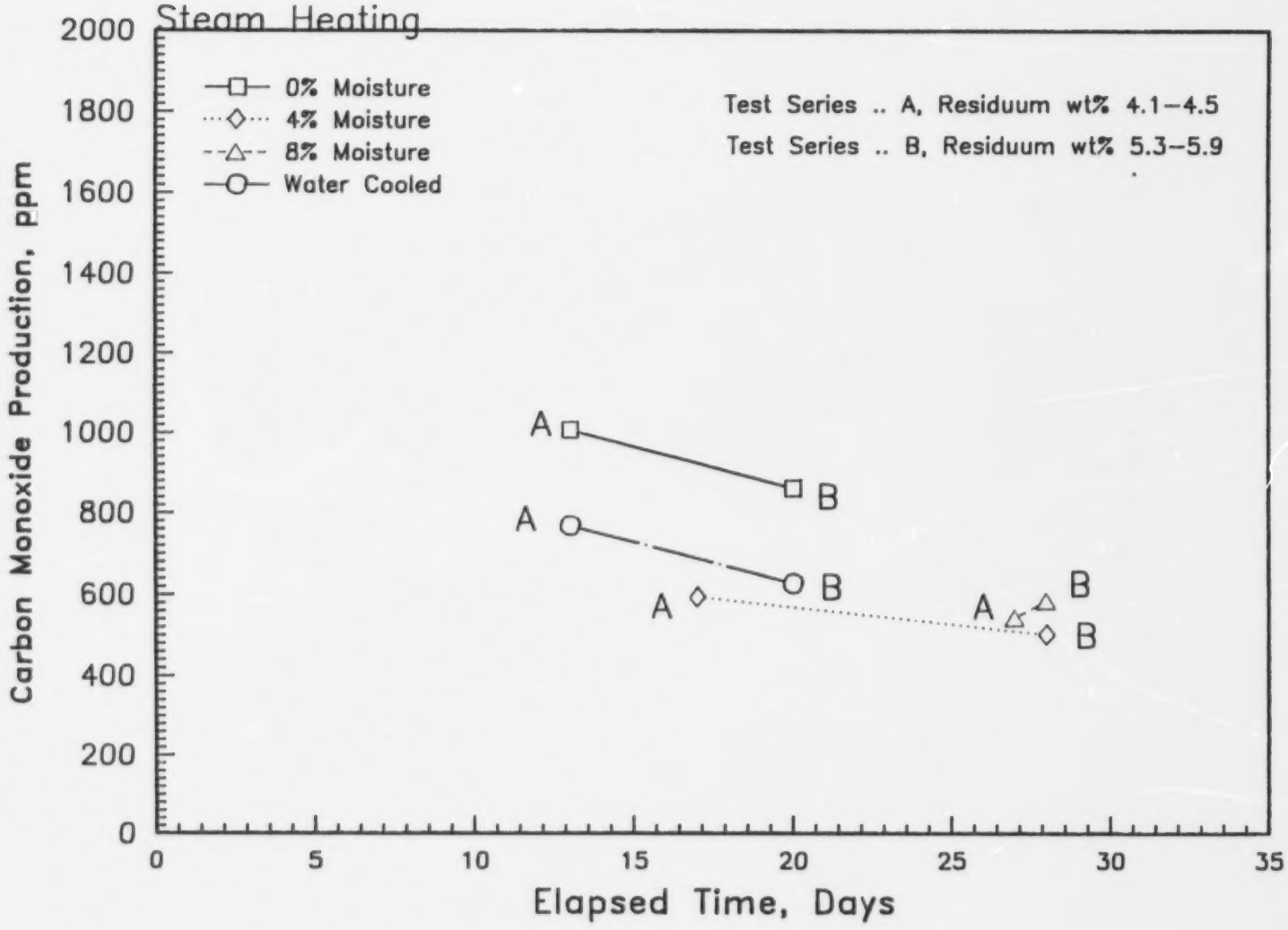


Figure 19
ANALYSIS OF HEAD GASES FOR OXYGEN SORPTION TEST

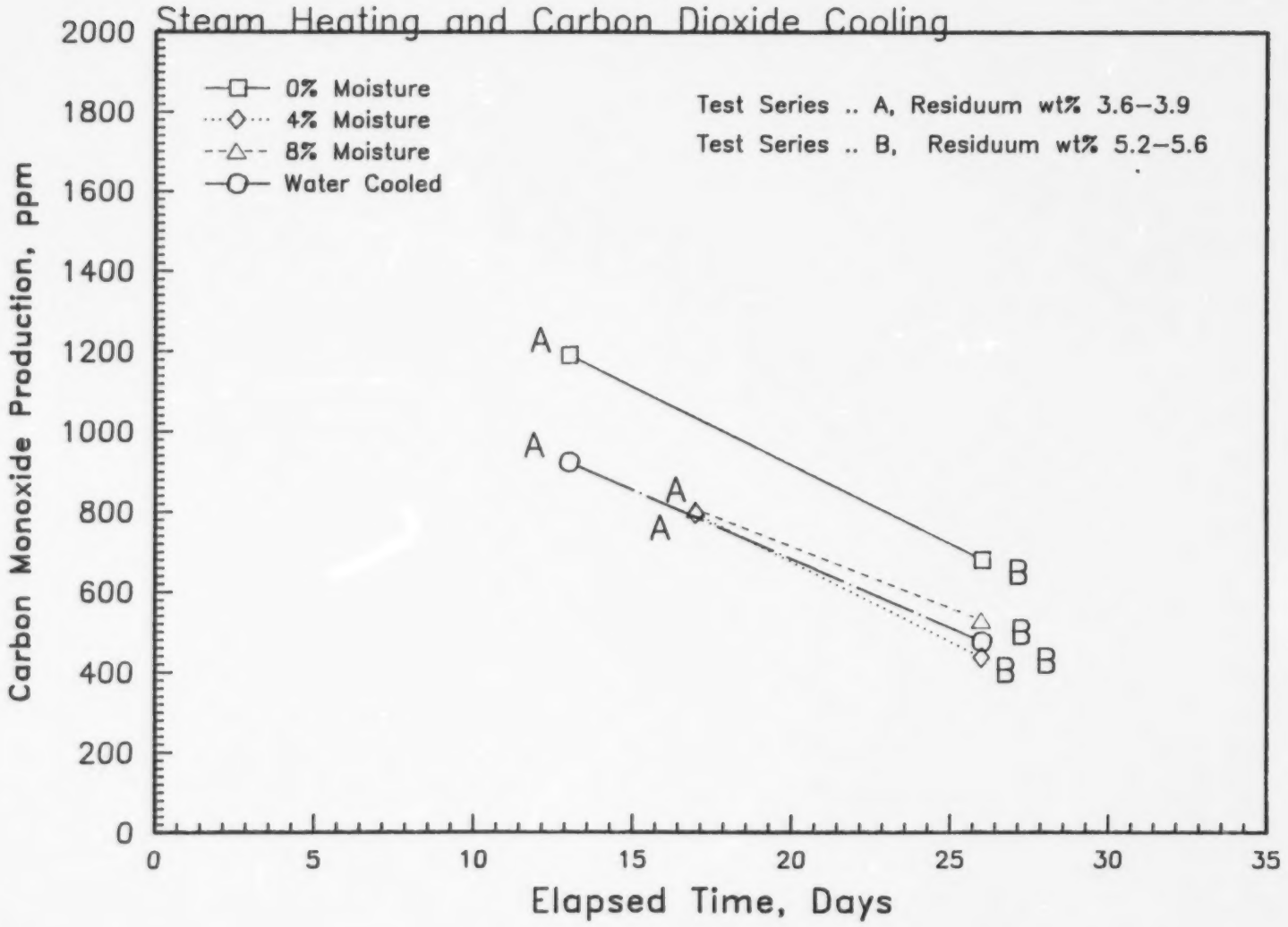


Figure 20
ANALYSIS OF HEAD GASES FOR OXYGEN SORPTION TEST

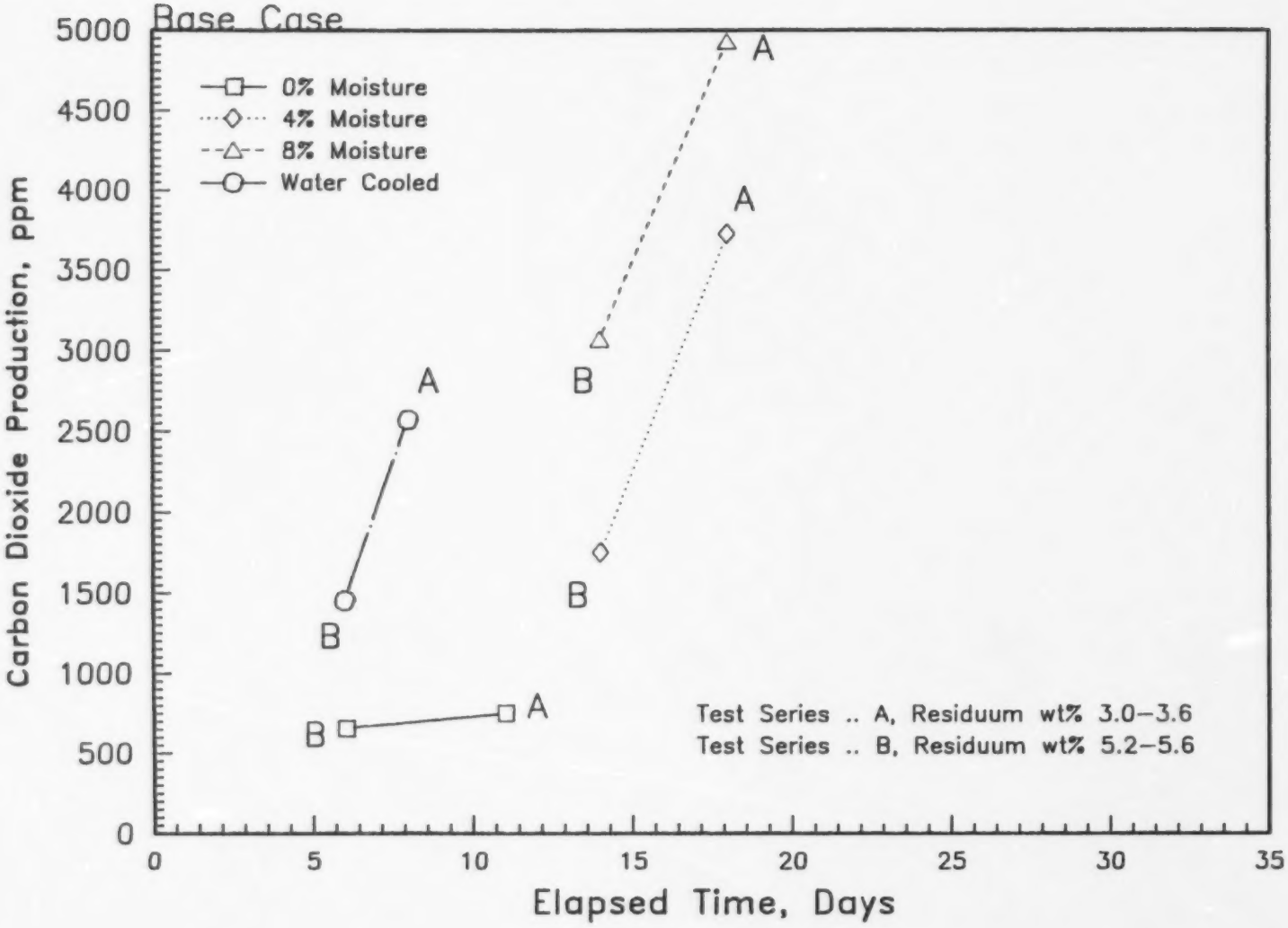


Figure 21
ANALYSIS OF HEAD GASES FOR OXYGEN SORPTION TEST

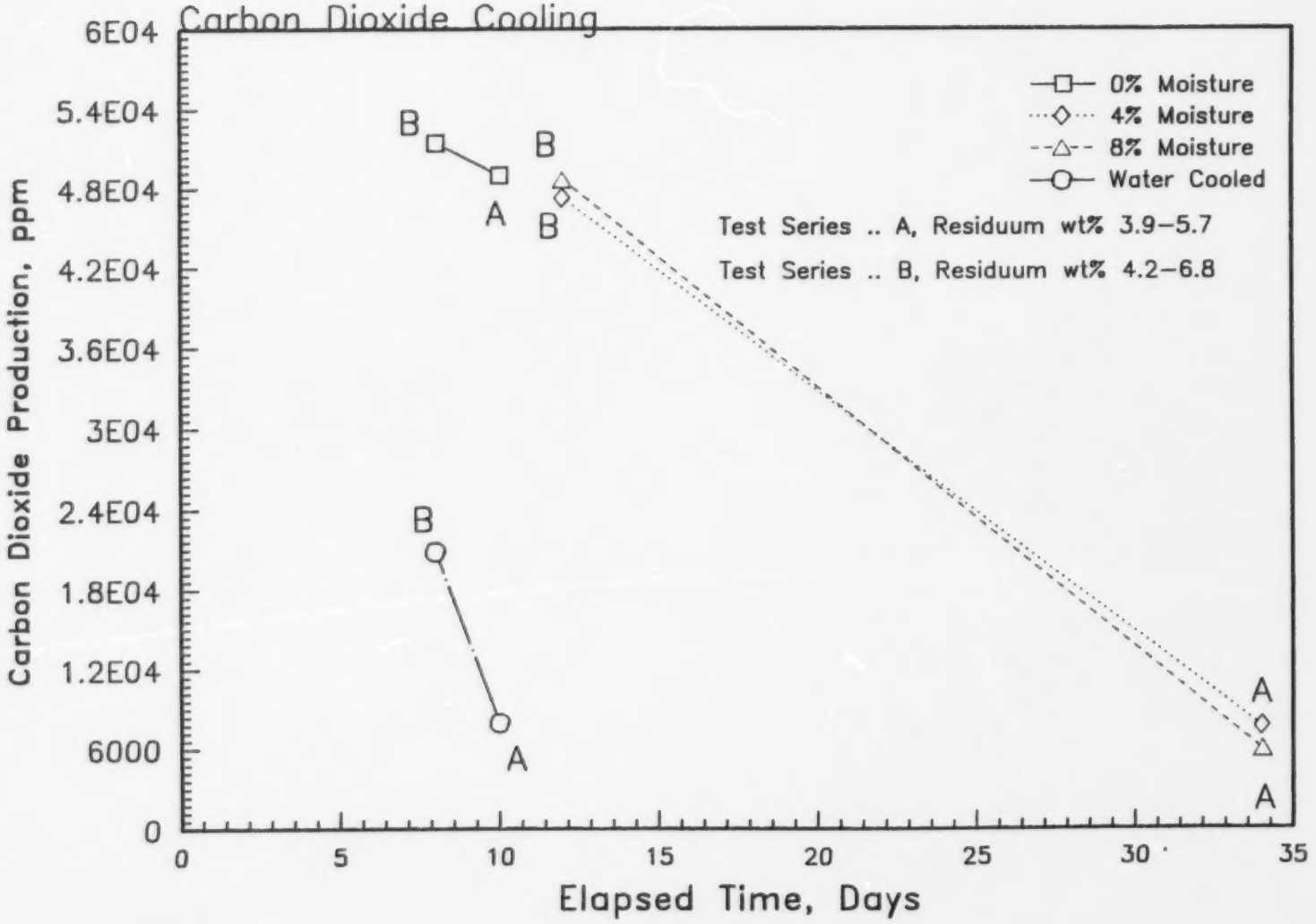


Figure 22
ANALYSIS OF HEAD GASES FOR OXYGEN SORPTION TEST

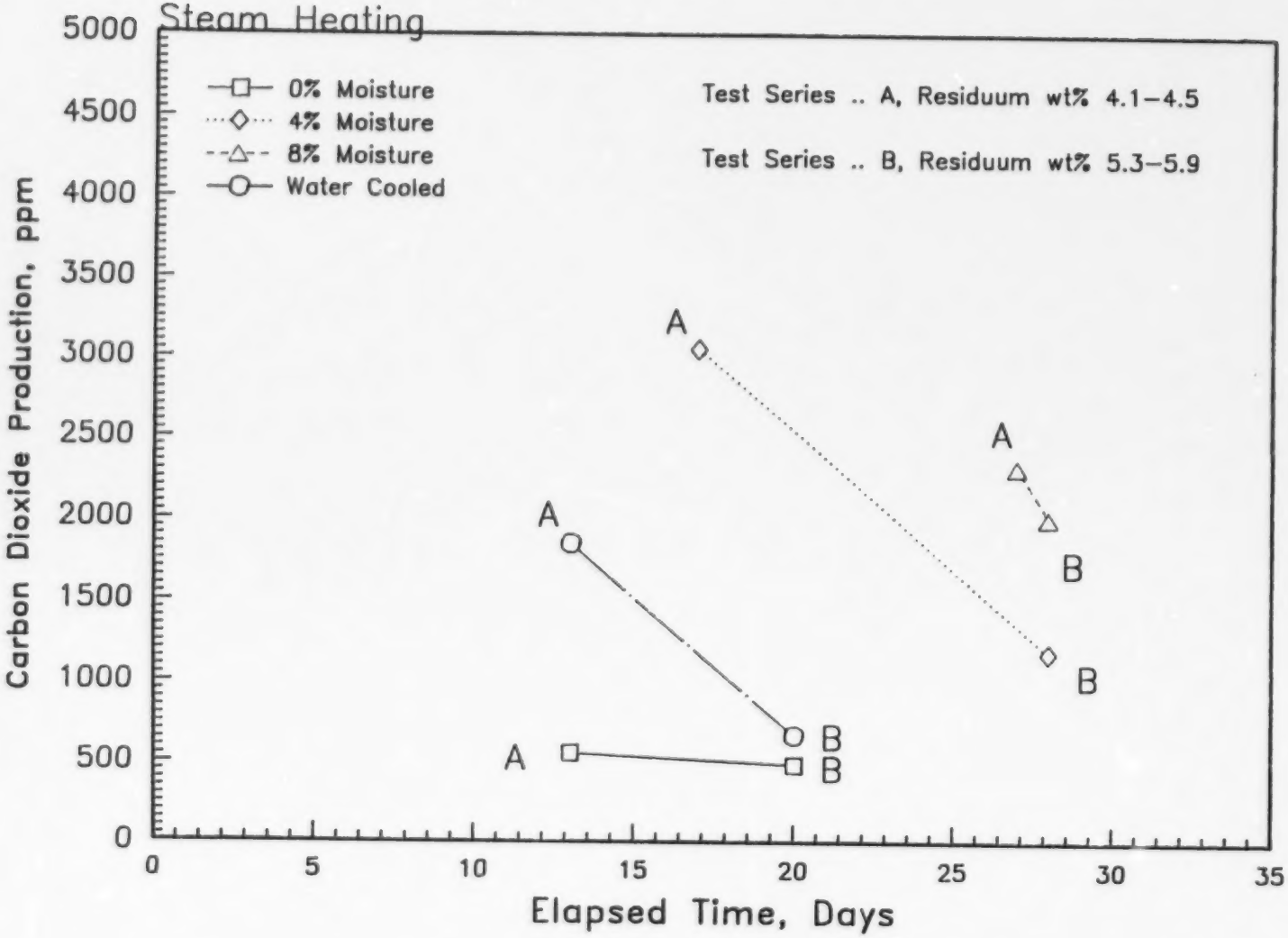


Figure 23
ANALYSIS OF HEAD GASES FOR OXYGEN SORPTION TEST

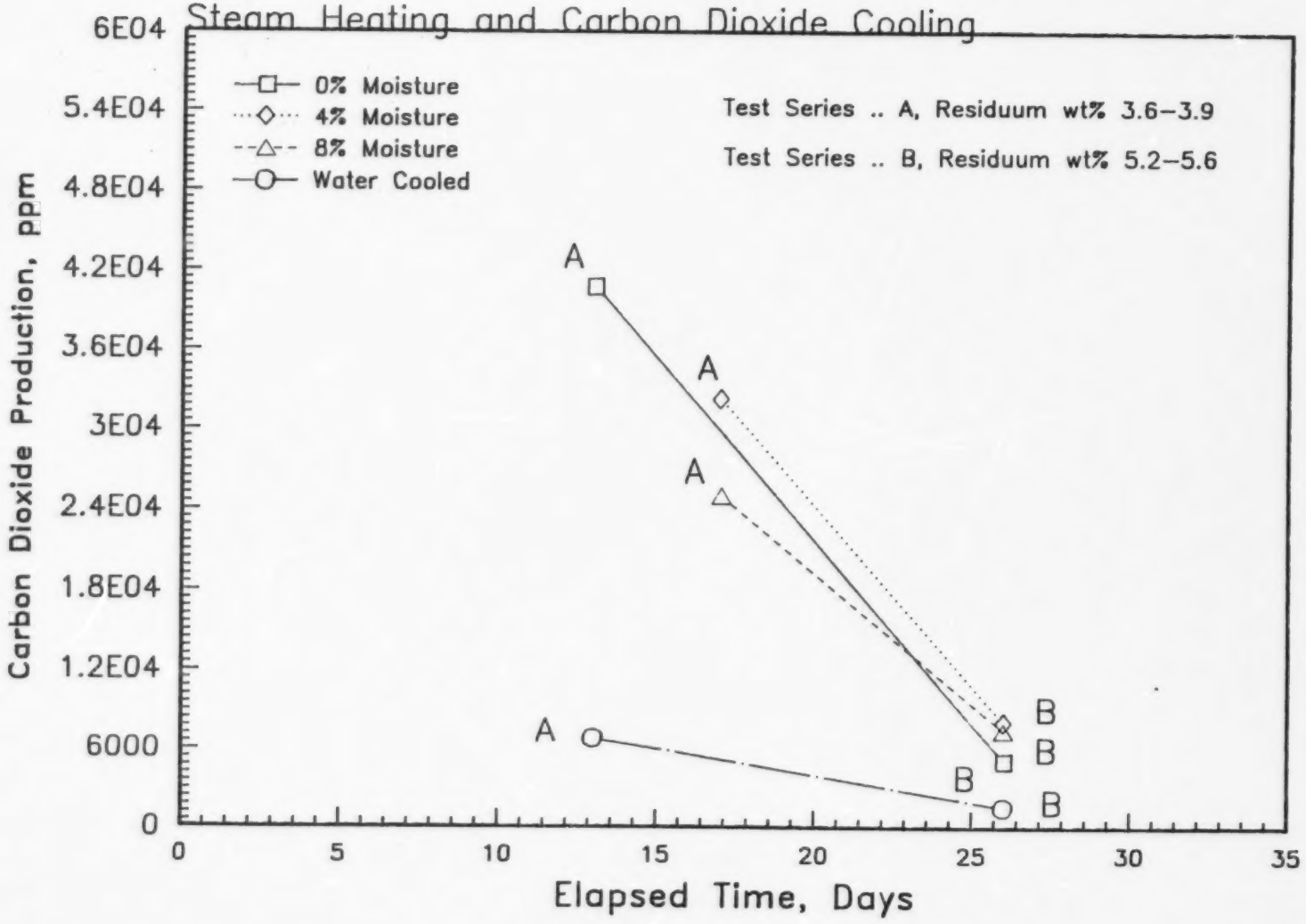


Figure 24
SPECIAL EXPERIMENTS: INVESTIGATING SAMPLE STORAGE METHODS ON OXYGEN SORPTION TEST

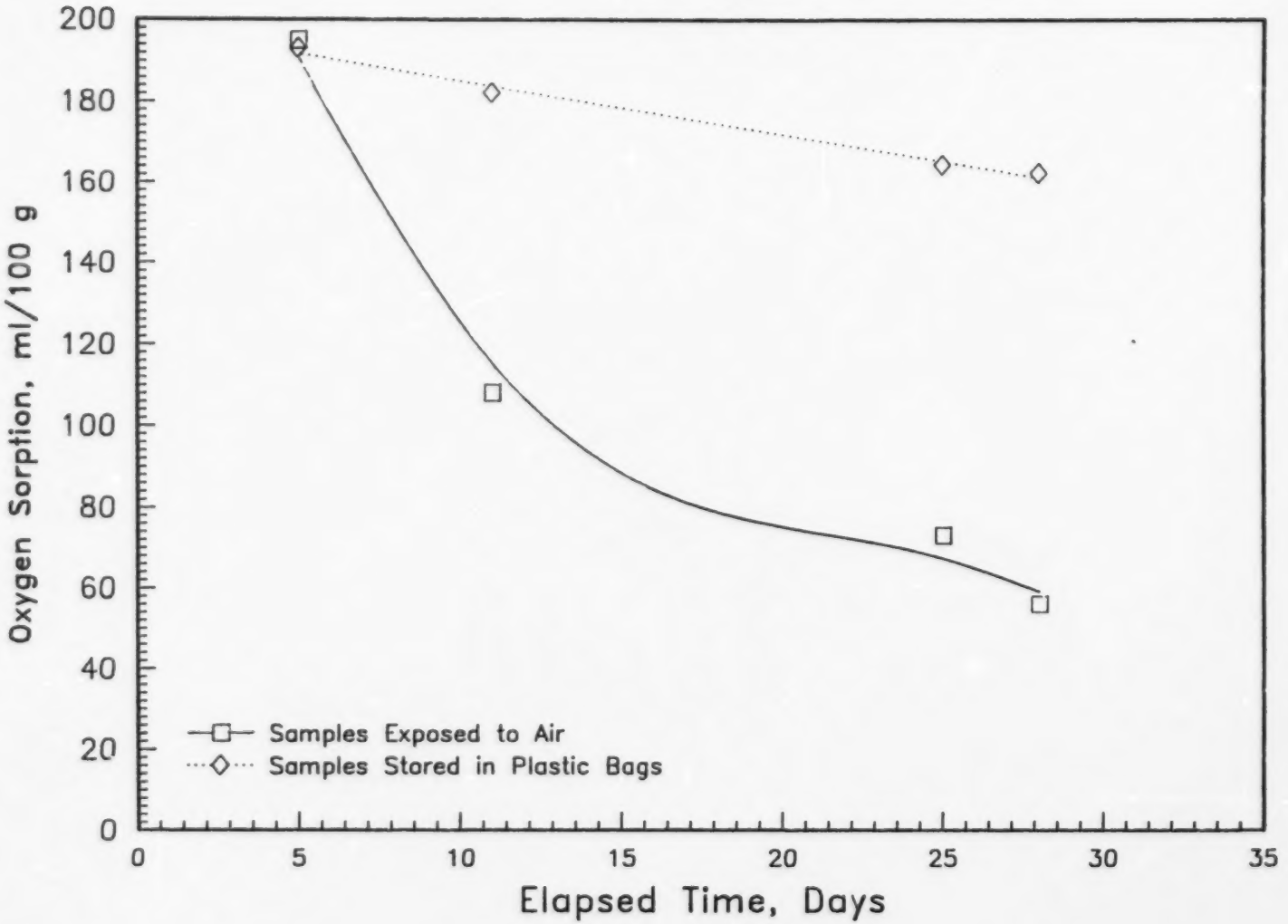


Figure 25
SPECIAL EXPERIMENTS: INVESTIGATING SAMPLE STORAGE METHODS ON OXYGEN SORPTION TEST

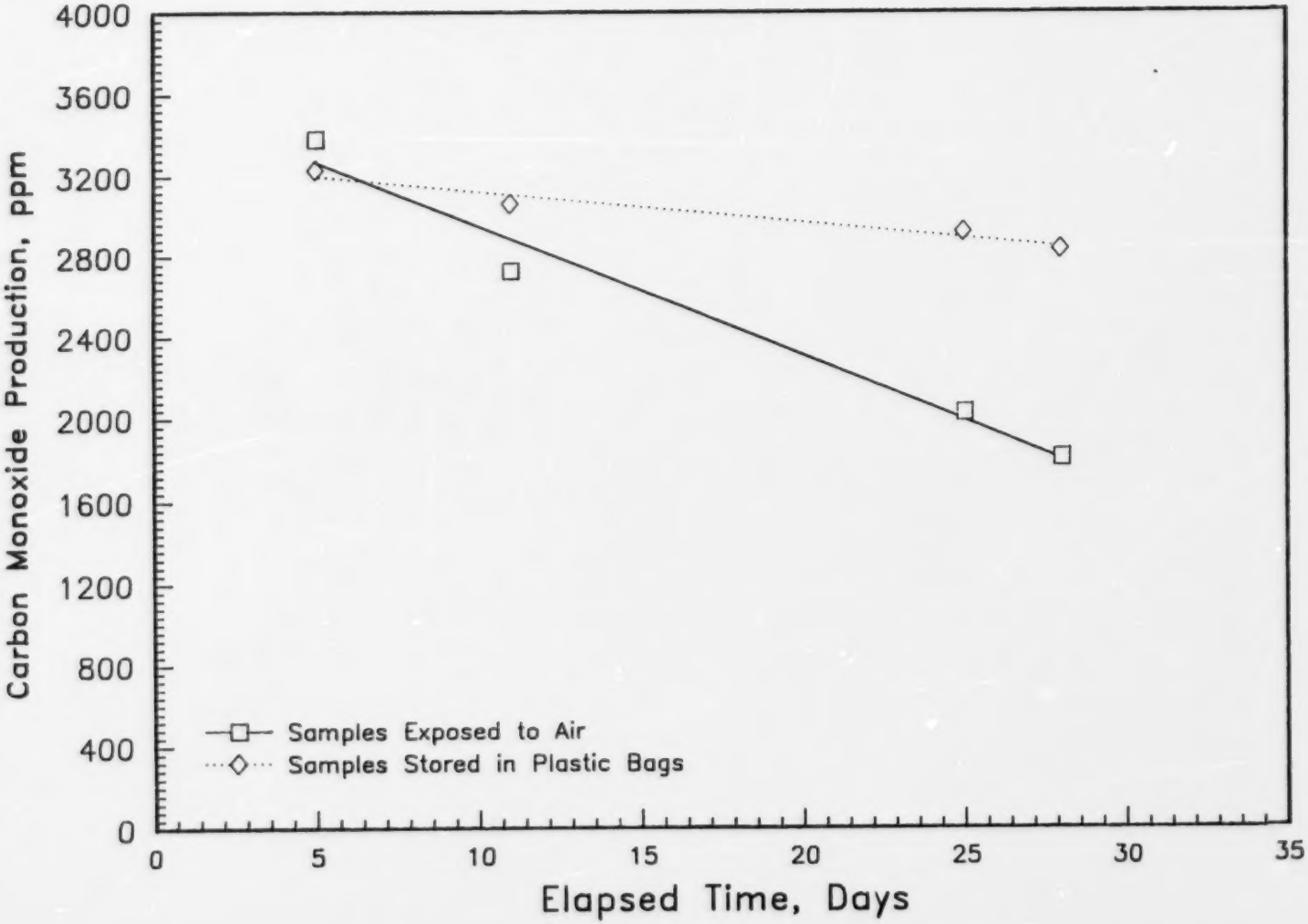


Figure 26
SPECIAL EXPERIMENTS: INVESTIGATING SAMPLE STORAGE METHODS ON OXYGEN SORPTION TEST

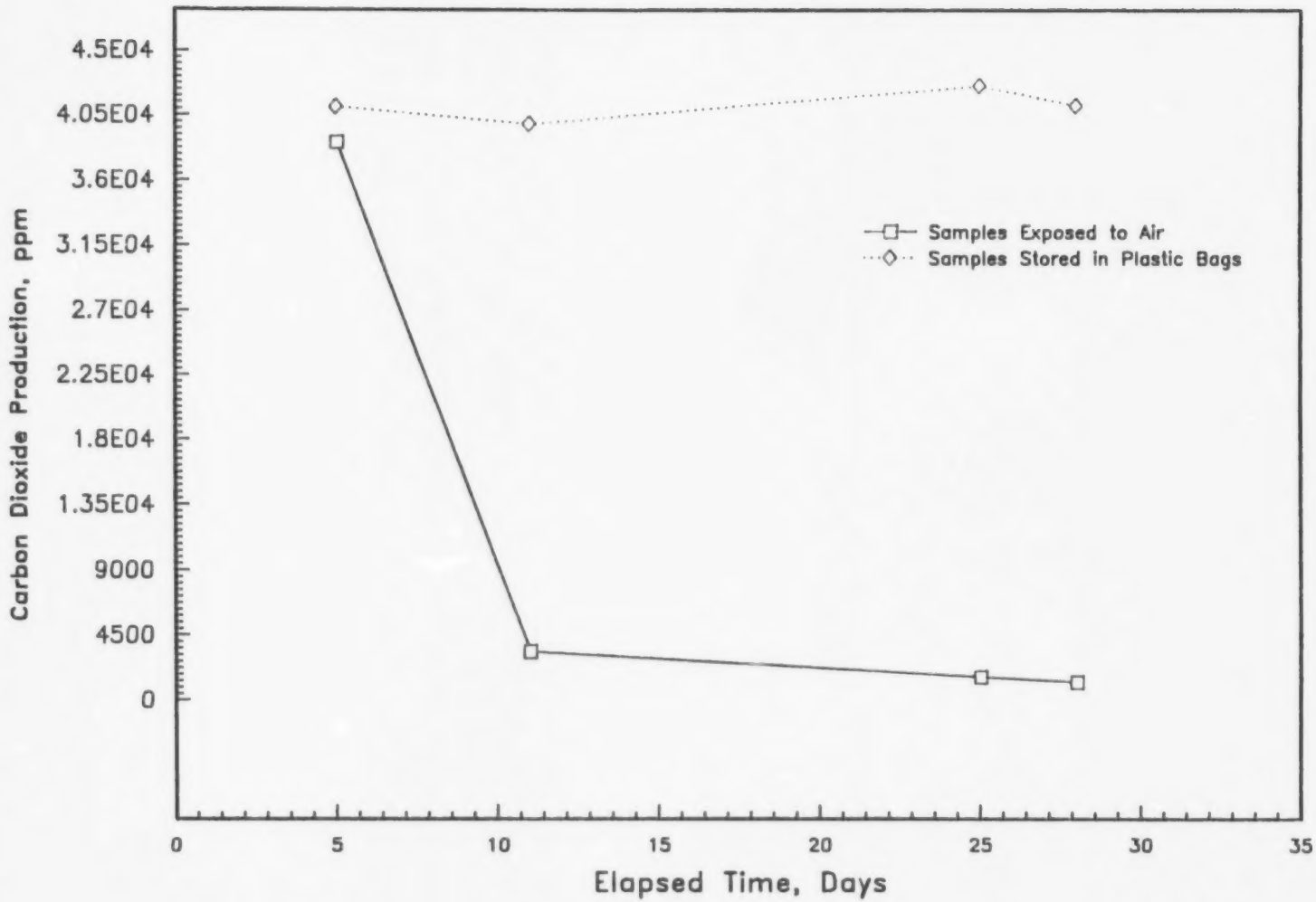


Figure 27
RELATIVE STABILITY OF UPGRADED PRODUCTS

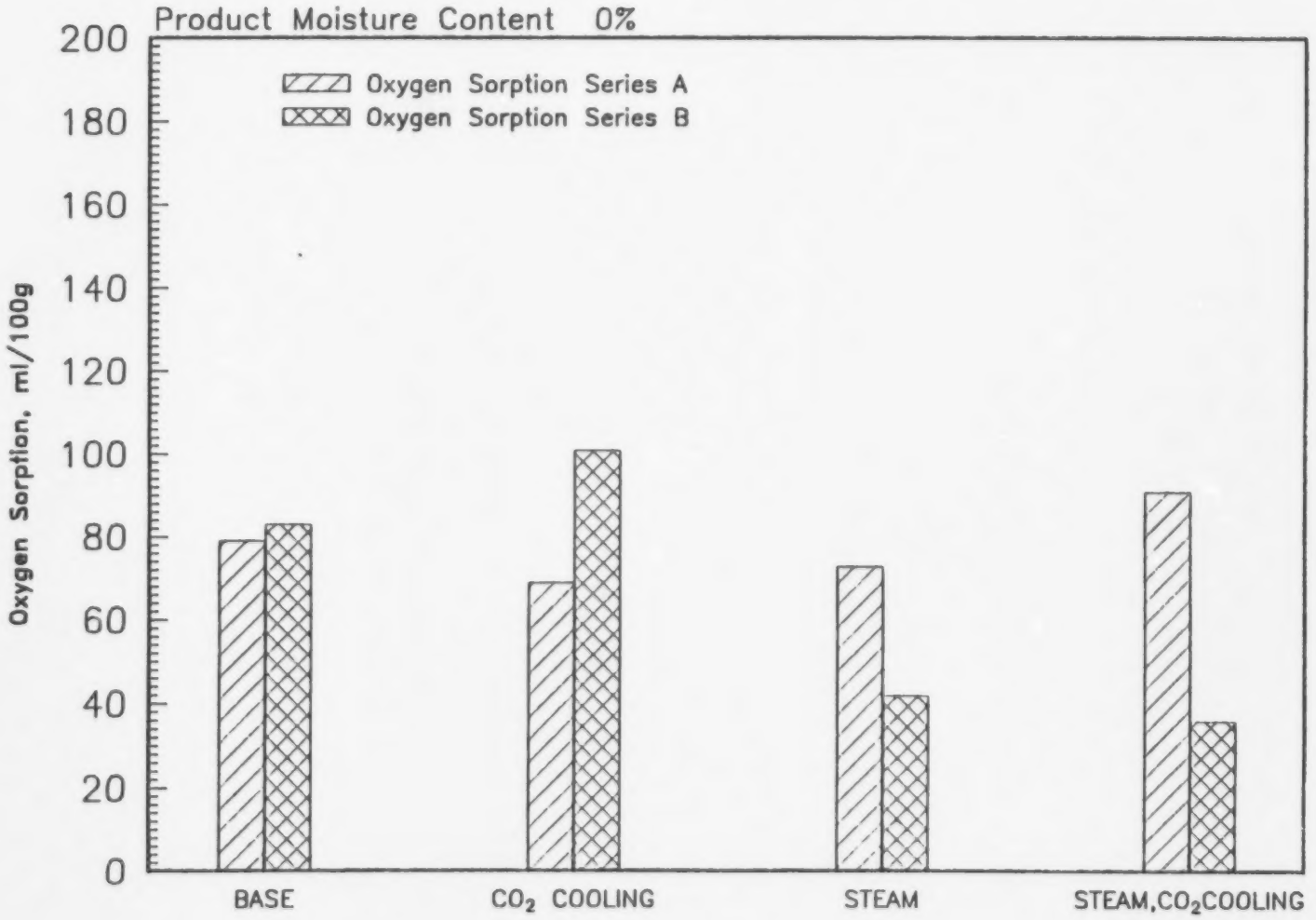


Figure 28
RELATIVE STABILITY OF UPGRADED PRODUCTS

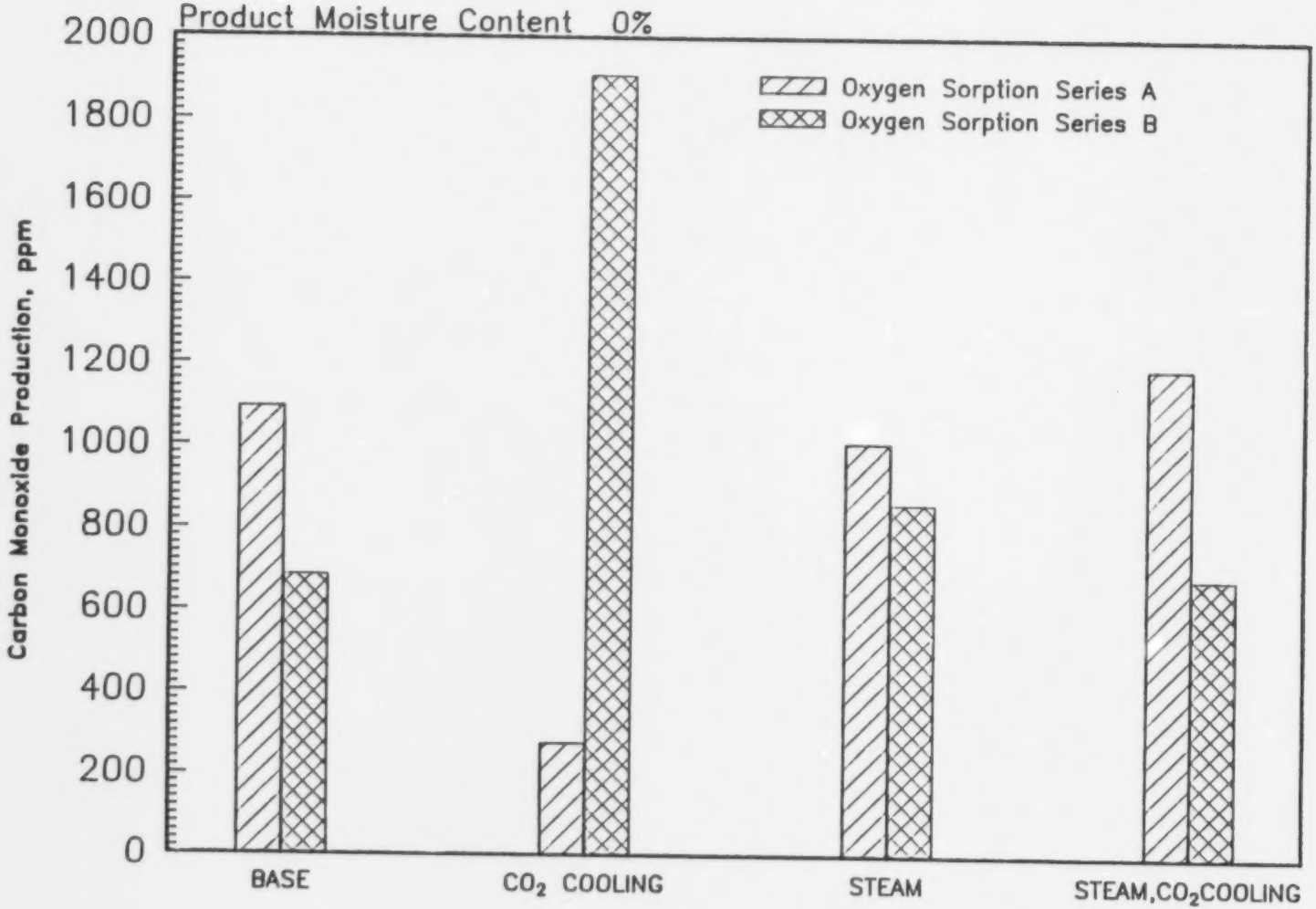


Figure 29
RELATIVE STABILITY OF UPGRADED PRODUCTS

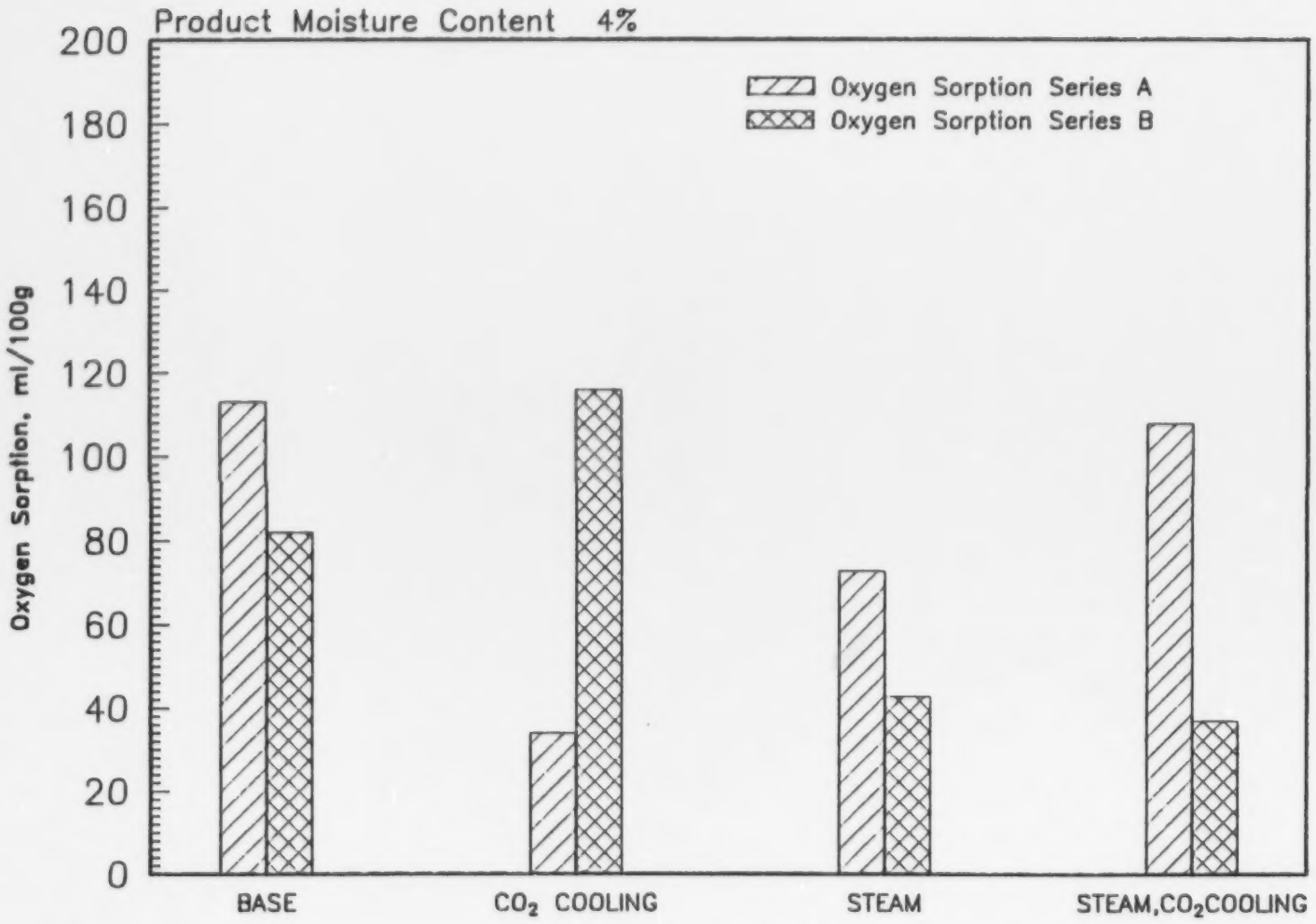


Figure 30
RELATIVE STABILITY OF UPGRADED PRODUCTS

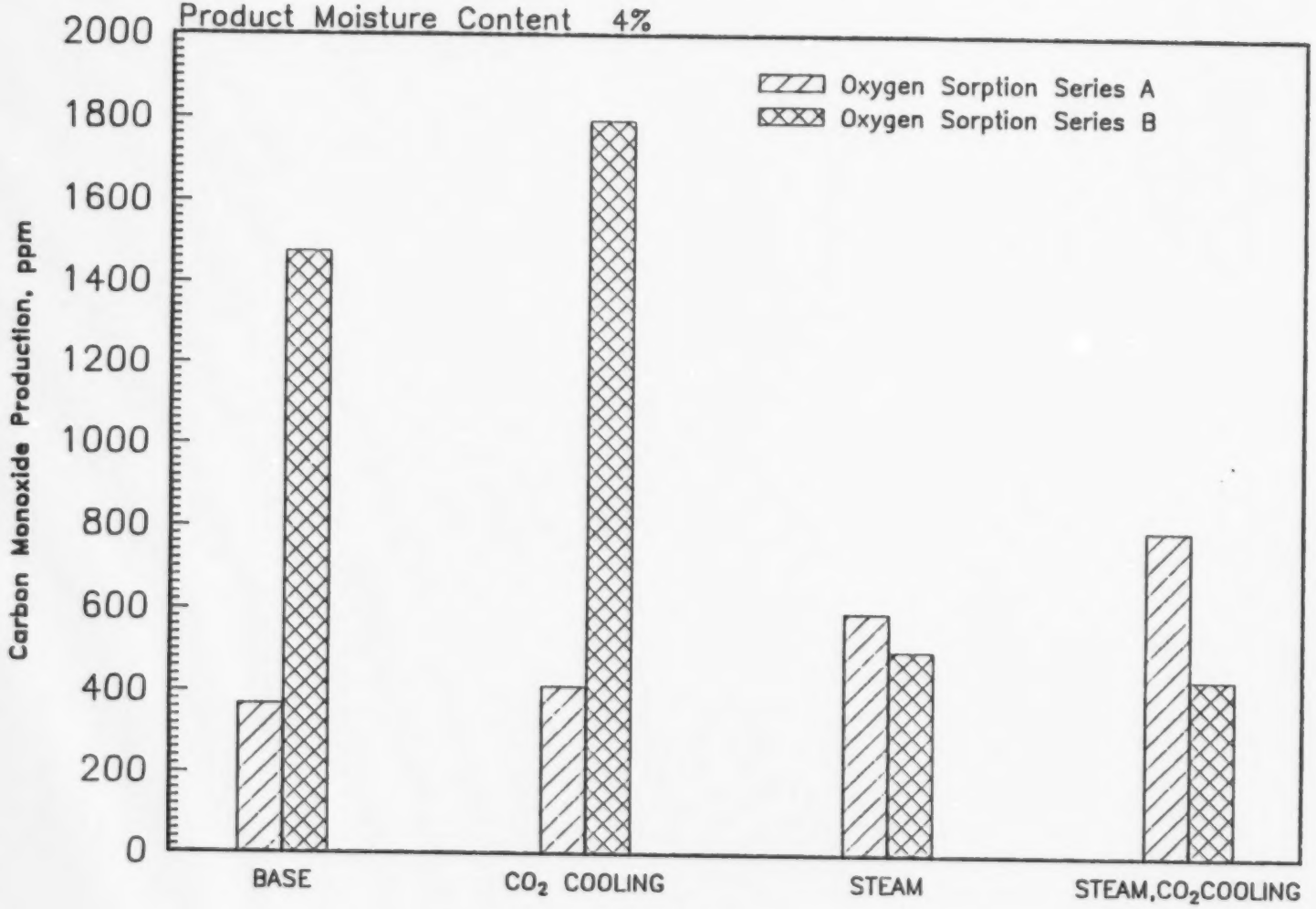


Figure 31
RELATIVE STABILITY OF UPGRADED PRODUCTS

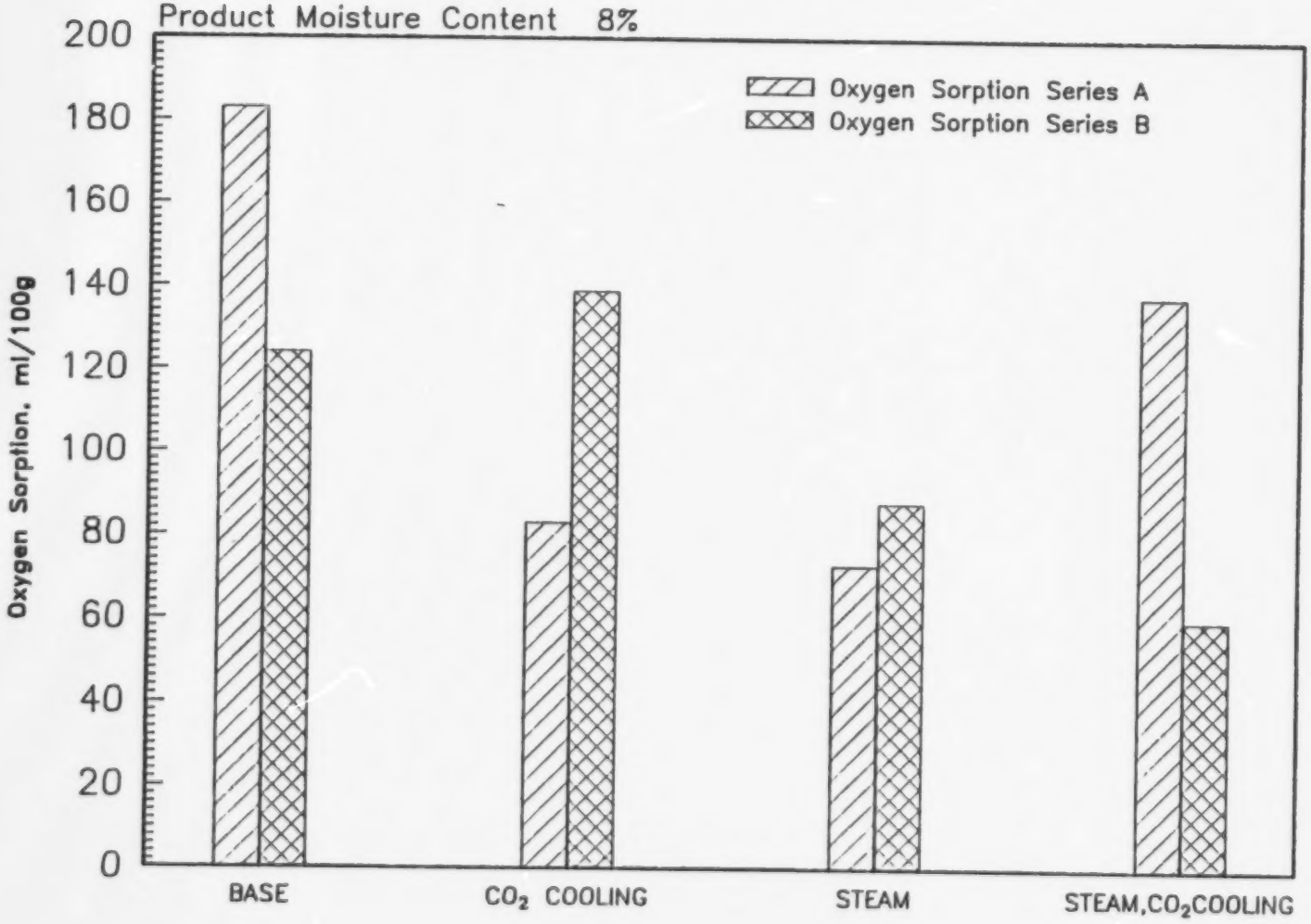


Figure 32
RELATIVE STABILITY OF UPGRADED PRODUCTS

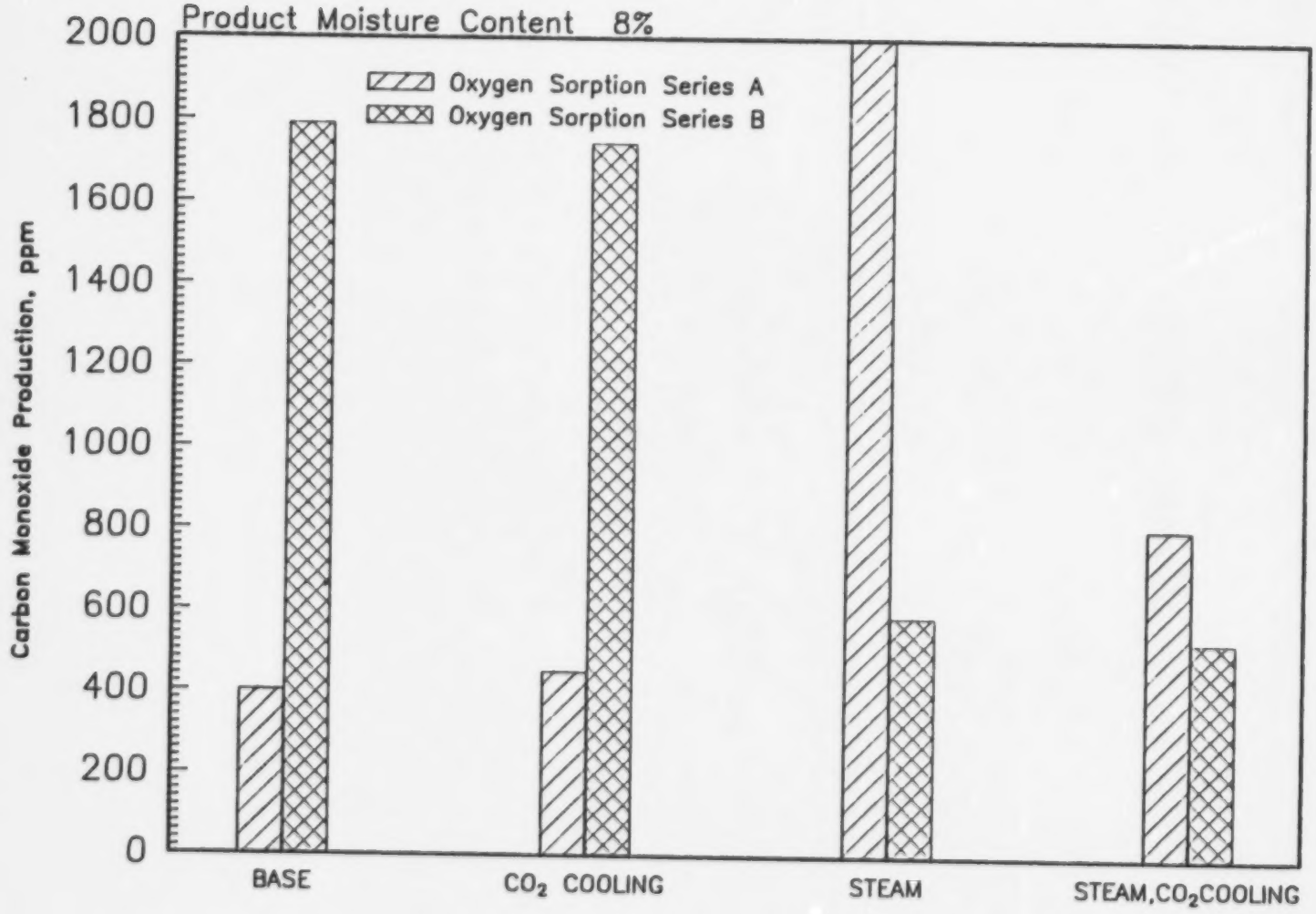


Figure 33
RELATIVE STABILITY OF UPGRADED PRODUCTS

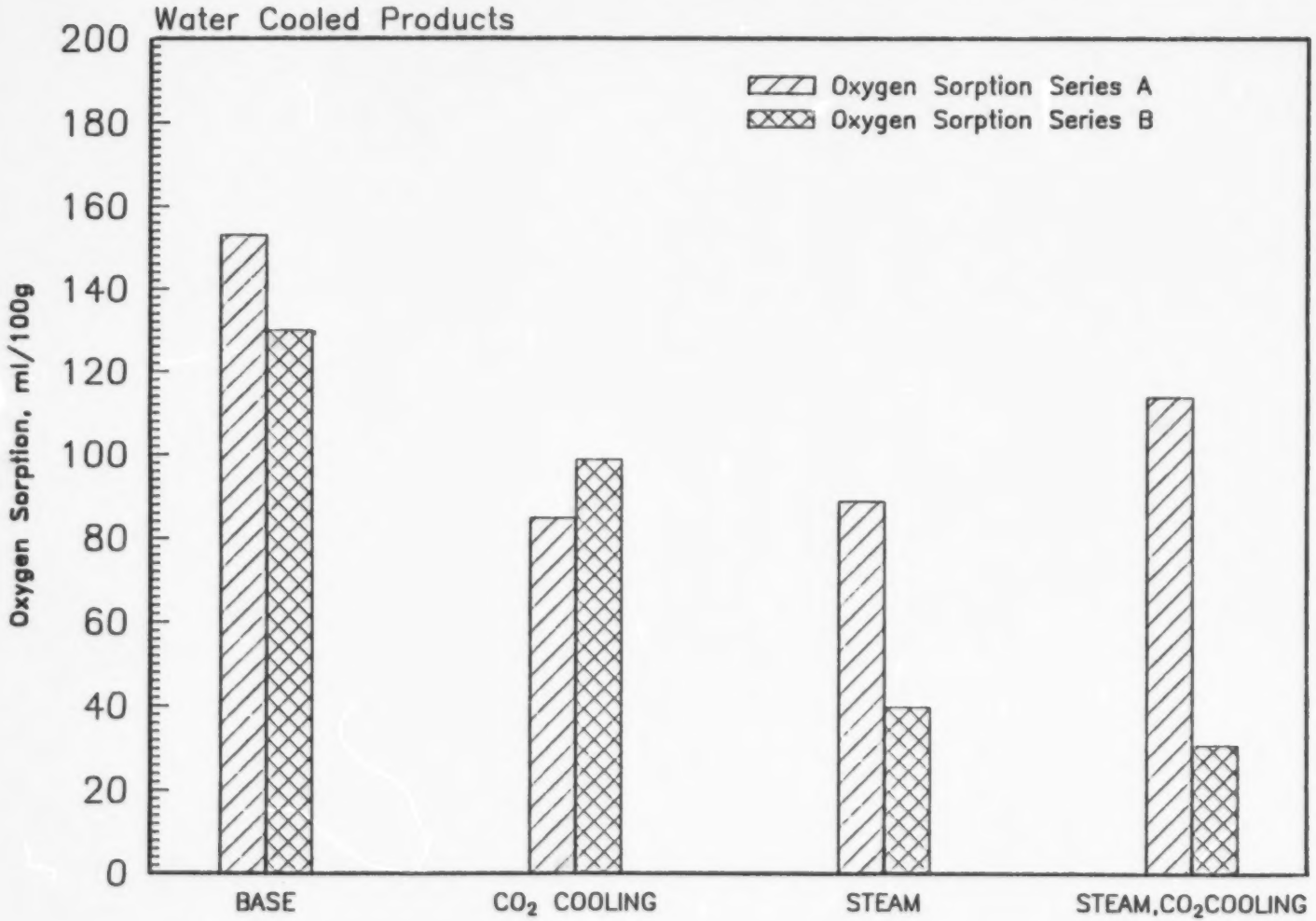


Figure 34
RELATIVE STABILITY OF UPGRADED PRODUCTS

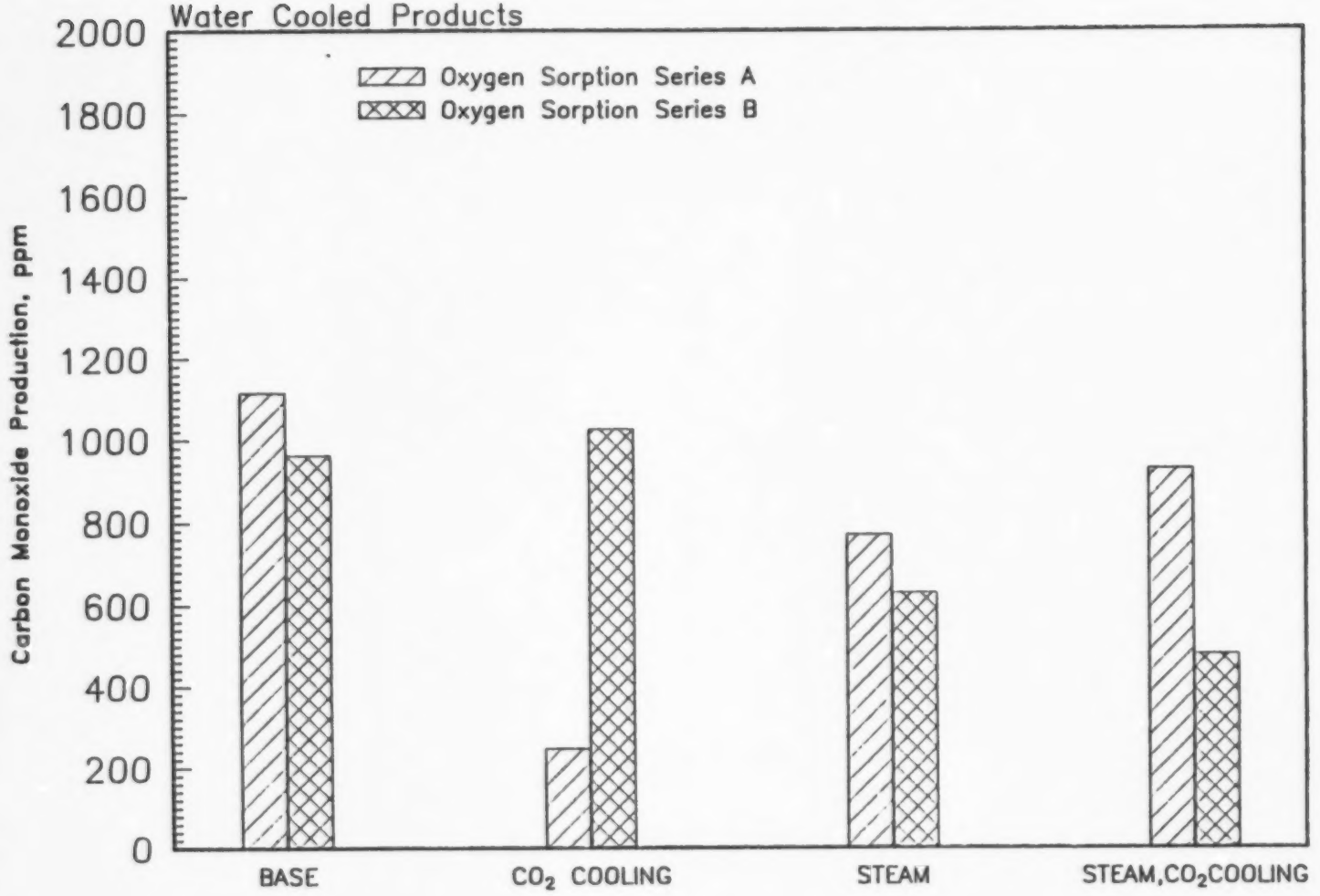


Figure 35
RELATIVE STABILITY OF UPGRADED PRODUCTS

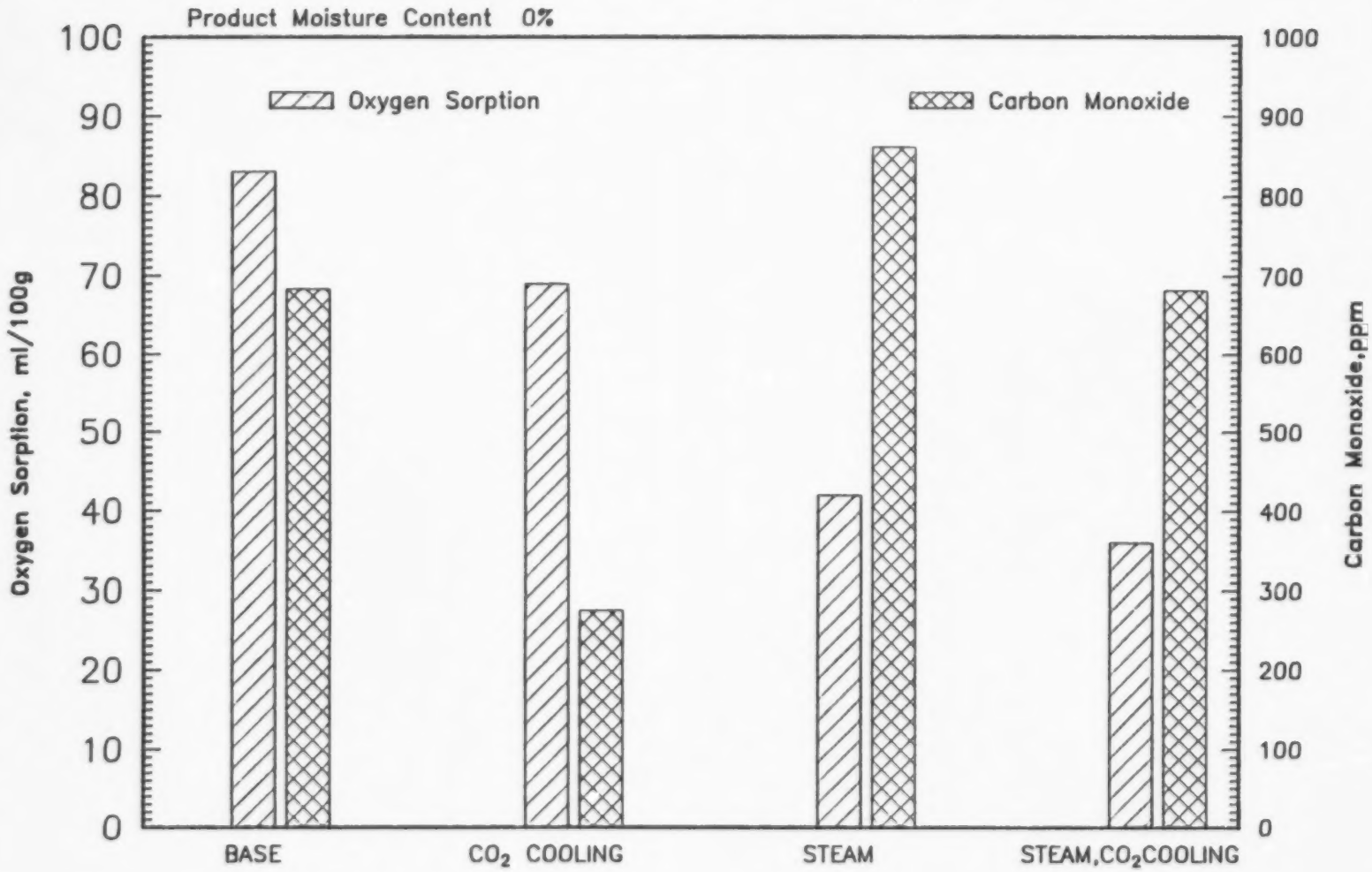


Figure 36
RELATIVE STABILITY OF UPGRADED PRODUCTS

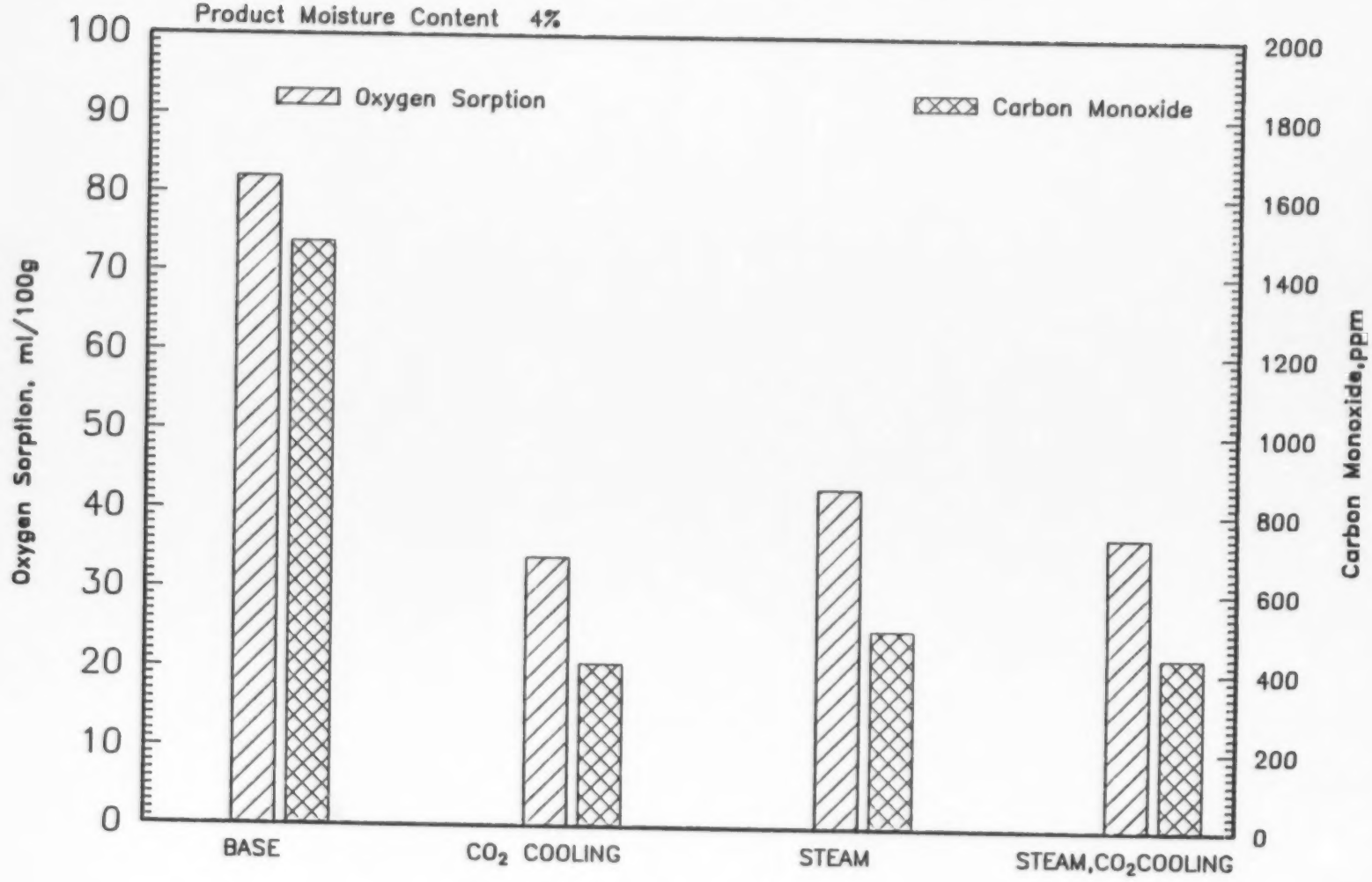


Figure 37
RELATIVE STABILITY OF UPGRADED PRODUCTS

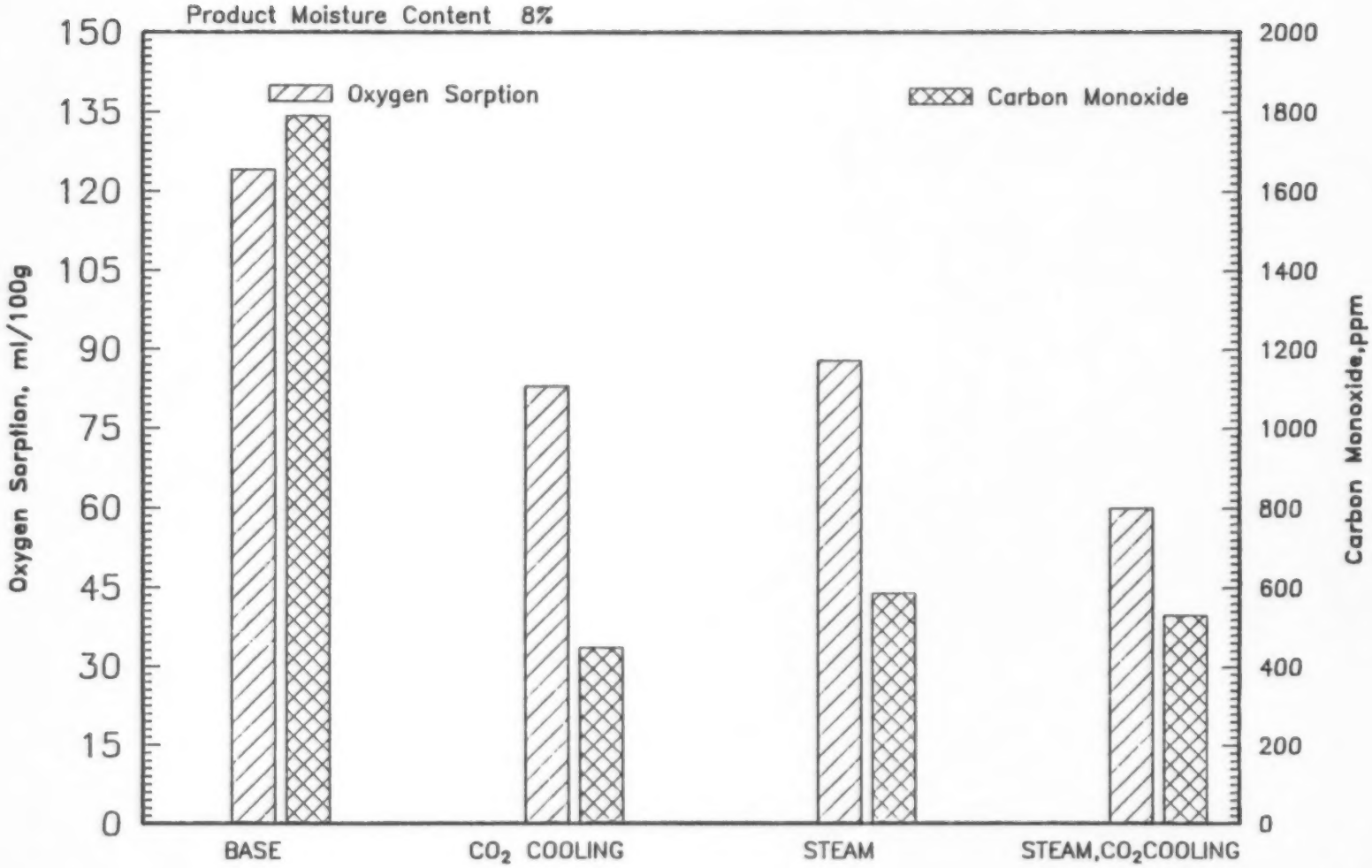
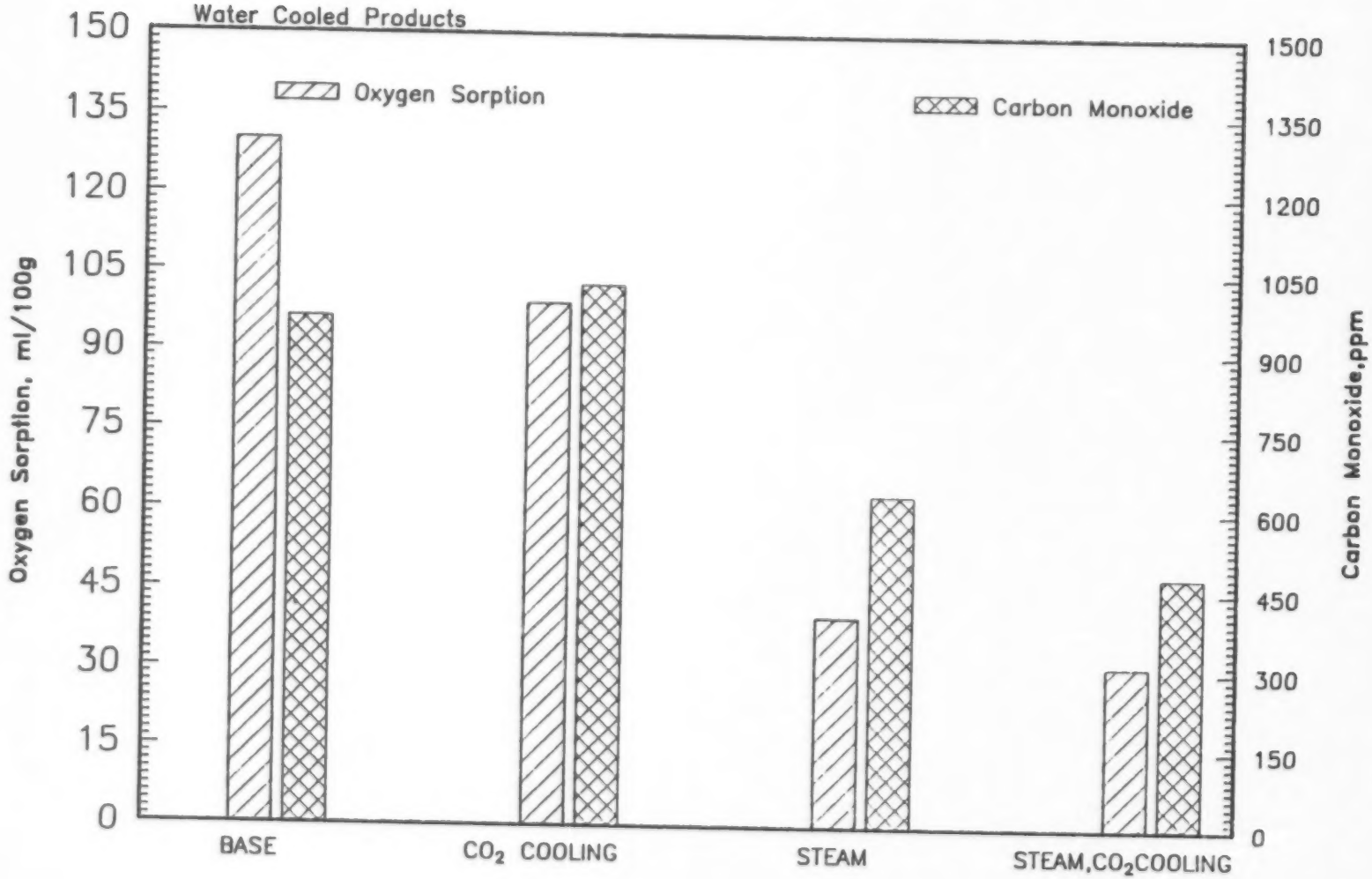


Figure 38

RELATIVE STABILITY OF UPGRADED PRODUCTS



Appendix 1

Work Statement

Appendix 1
Work Statement

The work shall be carried out in accordance with the following:

Task #1
Sample Collection

A one tonne sample of Obed Mountain coal (high volatile C bituminous) will be obtained for testing purposes. The sample will be screened to remove the +12mm particles. The -12mm bulk sample will be characterized with respect to:

- Proximate Analysis
- Calorific Value
- Equilibrium Moisture
- Oxygen Sorption
- CO Production
- Moisture Sorption

All these analyses will be carried at CMRC.

The residuum to be used, CENEX Asphalt, is already available in Gulf's Coal Research Program at Devon.

Task #2
Establishment of Base Case Conditions

The Gulf process proposed for this project is a two-stage process. The first stage involves heating the coal to desired temperature. The second stage involves applying residuum to the hot coal in a second drum. This process configuration is superior to a single-stage process because the cooler conditions in the second drum result in higher final residuum levels on the product. The proposed process configuration is shown in Figure 1. This configuration is currently installed in the Coal Mining Research Company's Devon pilot plant.

This task will product products against which the products of Task 3, 5, and 6 will be compared. This will enable us to directly compare the benefits resulting in Task 3, 5 and 6 to both the feed coal (Task #1) and the conventionally beneficiated coal (this task).

Test conditions will be:

1st Stage:	350°C product
2nd Stage:	4% applied residuum (CENEX)
	200°C product before cooling
	air or water cooling to 0.5, 4, 6 and 8% moisture.

Each product condition will be run twice to provide a measure of repeatability. All products will be analysed for:

- equilibrium moisture
- total moisture
- % residuum
- water sorption rate (% gain or loss over 24 hours at 75% rh and 21°C)
- O_2 sorption
- CO production

Task #3
CO_2 Cooling

In this task the benefits of CO_2 cooling will be investigated. The heat source for the 1st stage will be the current gas-fired burner. The 1st and 2nd stage processing will remain the same as in Task #2; however, cooling of the 200°C 2nd stage product will change for this task. The cooling stage will be either:

- CO_2 cooling without subsequent water treatment (i.e. 0.5% moisture product)
- CO_2 cooling combined with water treatment to produce 4, 6, and 8% moisture products.

All tests will be done in duplicate and all products will be analysed as per Task #2.

Task #4
Modification of Heat Source

In this task the heat source for the first stage operation will be changed from the current gas-fired burner to steam. Superheating of the steam will be required in order to heat the coal to a final first stage temperature of 350°C. Thus, modification of the current pilot plant equipment will be required. A small scale steam generator will be rented for carrying out steam heating experiments.

Task #5
Steam Heating

The modified equipment of Task #4 will be used to steam heat the coal in the first stage. Processing of the steam-headed coal in the second stage will be the same as in Task #2. CO_2 cooling will not be used in this task in order to evaluate the effects directly attributable to steam heating.

Test conditions will be:

1st Stage:	350°C product
2nd Stage:	4% applied residuum (CENEX)
	200°C product before cooling
	air or water cooling to 0.5, 4, 6 and 8% moisture.

Duplicate runs will be made for each product. All products will be analysed as per Task #2.

Task #6

Combined Steam Heating and CO_2 Cooling

After evaluation of the results from Tasks 3 and 5 a series of tests will be done combining 1st stage steam heating with CO_2 cooling of the 2nd stage product.

Test conditions will be:

1st Stage:	350°C product (steam heated)
2nd Stage:	4% applied residuum (CENEX)
	200°C product before cooling
	CO_2 cooling without subsequent water treatment
	CO_2 cooling following by water treatment to 0.5, 4, 6 and 8% moisture.

All products will be analysed as per Task #2.

Task #7

Evaluation of Results and Final Report

Results obtained from all tasks will be compiled, compared and analyzed. The final report will be supported by tables, graphs and figures as appropriate.

Appendix 2

Steam Heating System Calibrations of
Natural Gas Regulator and Combustion Air Damper Fan

Appendix 2
Steam Heating System
Calibrations of Natural Gas Regulator and
Combustion Air Damper Fan

Calibration of Gas Regulator Orifice

Position of Valve	Natural Gas Flow l/min
1/8 cycle open	12.85
1/4 cycle open	16.36
3/8 cycle open	22.50
1/2 cycle open	27.69
3/4 cycle open	31.04
1.0 cycle open	35.02
1-1/4 cycle open	39.28
1-1/2 cycle open	42.51
1-3/4 cycle open	45.02
2 cycle open	47.26

Calibration of Combustion Air Fan

Fan Damper Position	Air Velocity m/s	Air Flow Rate m^3/m
closed	0.05	0.024
1/4 open	0.65	0.306
1/2 open	1.10	0.518
3/4 open	1.35	0.636
full open	1.60	0.754

Appendix 3

Operating Conditions of the Steam Heating System

Appendix 3

Operating Conditions of the Steam Heating System

Coal feed rate, ave	=	36.0 kg/h or 600 g/min
Coal % Moisture Content, ave	=	15.0 %
Dry coal feed rate (36 x 0.85)	=	30.6 kg/h or 510 g/min
Moisture feed rate (36 x 0.15)	=	5.4 kg/h or 90 g/min
Natural gas flow rate	=	45 l/min
Combustion air flow rate, 20° C	=	450 l/min
Steam flow rate	=	39 kg/h or 650 g/min
Steam temperature	=	125°C
Product temperature	=	350°C
Exhaust gas temperature	=	490°C

Theoretical combustion air requirement

$CH_4 + 2O_2$	=	$CO_2 + 2\ H_2O$
1 g mole + 2 g mole	=	1 g mole + 2 g mole
1 l + 2 l	=	1 l + 2 l
1 l + 9.52 air	=	1 l + 2 l

For 45 l/min natural gas air required	=	45 x 9.52
	=	428.4 l/min
Actual air flow rate	=	450 l/min
Therefore, excess air (450 - 428.4) flow rate	=	21.6 l/min

Volumetric Flow of Combustion Products at 20°C

Excess air	=	21.6 l/min
Nitrogen (428.4 x 0.79)	=	338.4 l/min
Carbon dioxide	=	45.0 l/min
Water vapour from combustion of gas	=	90.0 l/min
Water vapour from coal moisture $\frac{90}{18} \times 22.4 \times \frac{293}{273}$	=	120.2 l/min
Water vapours from injected steam $\frac{650}{18} \times 22.4 \times \frac{293}{273}$	=	868.2 l/min
Total flow rate as combustion gases	=	1,483.4 l/min
O_2 flow from excess air 21.6 x 0.21	=	4.54 l/min
Volumetric % O_2 in combustion gases $4.54 \times \frac{100}{1,483.4}$	=	0.3%
Volumetric % steam flow in combustion gases $(90 + 120.2 + 868.2) \times \frac{100}{1,483.4}$	=	72.7%

Heat Balance

Thermodynamic data	=	kJ/kg °C
Specific heat of air	-	1.04
Specific heat of steam	=	2.07
Specific heat of water	=	4.187
Specific heat of dry coal	=	1.256
Latent heat of water	=	2,257.3 kJ/kg

Heat Input

Calorific value of natural gas	=	37.23 kJ/l
Gas flow rate	=	45.0 l/min
Heat of combustion 45 x 37.23	=	1,675.4 kJ/min
	or	100,6521.0 kJ/h

Heat Taken

By dry Coal 1.256 x 30.6 (350 - 20)	=	12,683.1 kJ/h
By moisture in coal at 100°C (100-20) x 5.4 x 4.187	=	1,808.8 kJ/h
By moisture to evaporate at 100°C (5.4 x 2,257.3)	=	12,189.4 kJ/h
By moisture vapour from 100°C to 490°C (5.4 x (490-100) x 2.07	=	4,359.4 kJ/h
By injected steam at 125°C to 490°C 39 x (490-125) x 2.07	=	29,466.5 kJ/h

Gaseous Products

Total nitrogen (338.4 + 17.06)	=	355.46 l/min
or $355.46 \times \frac{273}{293} \times \frac{1}{22.4} \times \frac{28}{1000} \times 60$	=	24.8 kg/h
Oxygen flow rate	=	4.54 l/min
or $(4.54 \times \frac{273}{293} \times \frac{1}{22.4} \times \frac{32}{1000} \times 60$	=	0.36 kg/h
Carbon dioxide flow rate	=	45.0 l/min
$45 \times \frac{273}{293} \times \frac{1}{22.4} \times \frac{44}{1000} \times 60$	=	4.94 kg/h
Heat taken by gaseous product		
30.1 x 1.04 x (490-20)	=	14,712.9 kJ/h
Total heat taken	=	75,220.1 kJ/h
Thermal Efficiency	=	75%

Notes

1. cps (kJ/kg°C) are average values for different mixtures of gases.

2. Humidity of combustion air varied from about 30% to 40% on different days. Moisture present in air very small and not taken into consideration.

Operating Conditions for Heating of Coal - Base Test

Natural gas flow rate, at 20°C	=	30 l/min
Combustion air flow rate, at 20°C	=	306 l/min
Theoretical combustion air requirement		
$Ch_4 + 2\ O_2$	=	$CO_2 + 2\ H_2O$
1 l + 0.52 l air	=	1 l + 2 l
For 30 l/min air required	=	285.6 l/min
Excess air flow rate (306.285.6)	=	20.4 l/min

Volumetric Flow of Combustion at 20°C

Excess air	=	20.4 l/min
Nitrogen (285.6 x 0.79)	=	225.6 l/min
Carbon dioxide	=	30.0 l/min
Water vapour from coal moisture $\frac{90}{18} \times 22.4 \times \frac{293}{273}$	=	120.2 l/min
Water vapour from combustion	=	60 l/min
Total flow rate, at 20°C	=	456.2 l/min
Oxygen flow in excess air (20.4 x 0.21)	=	4.3 l/min
% Oxygen in product gases $\frac{4.3}{456.2} \times 100$	=	0.94%

Appendix 4

Method Used to Calculate Sorption of Oxygen and Production of Carbon Monoxide and Dioxide

Appendix 4
Procedure to Calculate Oxygen Sorption

Method of Calculation

A. When % carbon dioxide + carbon monoxide in head gas < 0.5

Available Data Sample #52-0-A17-UT (Air Exposed)

Volume of cylinder, ml		=	21,235
Test sample of coal, g		=	1,500
Density coal		=	1.36
Volume of air in cylinder $21{,}235 - (\frac{1{,}500}{1.36})$		=	20,132
% Oxygen in air		=	20.93
% Nitrogen in air		=	79.07
% Oxygen after 96 h in head gas		=	14.03
Initial volume of oxygen in cylinder, ml $20{,}132 \times 0.2093$		=	4,214
Initial volume of nitrogen in cylinder, ml $20{,}132 \times 0.7907$		=	15,918
Say O_2 left in cylinder after 96 h		=	x ml
Then $\frac{100 \times x}{(15{,}918 + x)}$	= 14.03		
$100x$	= $14.03\,(15{,}918 + x)$		
$85.97x$	= 223,330		
x	= 2,598		
Total oxygen consumed	= 4,214 - 2,598	=	1,616 ml
or	= 108/100 g of coal		

Note: Volume of CO + CO_2 generated was too small and therefore not included in calculations.

B. When % carbon dioxide + carbon monoxide in head gas > 0.5

Available data of sample #52-0-A17-UT (Nitrogen)

Volume of cylinder, ml	=	21,435
Test sample of coal, g	=	1,500
Density coal	=	1.36
Volume of air in cylinder $21{,}435 - (\frac{1{,}500}{1.36})$	=	20,332
% Oxygen in air	=	20.93
% Nitrogen in air	=	79.07
% Oxygen after 96 h in head gas	=	8.35
% Carbon dioxide + carbon monoxide in head gas	=	4.29
Initial volume of oxygen in cylinder, ml	=	4,256
Initial volume of nitrogen in cylinder, ml	=	16,076
Say O_2 left in cylinder after 96 h	=	x ml
$CO + CO_2$ Volume after 96 h Exposure	=	y

Then:

$$\frac{100 \times x}{(16{,}076 + x + y)} = 8.35 \qquad (1)$$

$$\frac{100 \times y}{(16{,}076 + x + y)} = 4.29 \qquad (2)$$

$$\frac{x}{y} = \frac{8.35}{4.29}$$

or $x = 1.946\ y$

or $y = 0.514\ x$

Substituting value of y in equation (1)

$$\frac{100 \times x}{(16{,}076 + x + 0.514x)} = 8.35$$

$$100x - 12.64x = 134{,}235$$

$$87.36x = 134{,}235$$

$$x = 1{,}537$$

O_2 absorbed = 4,256 - 1,537 = 2,719

O_2 absorbed/100 g coal = 181.3 ml

Appendix 5

Equilibrium Moistures of Upgraded Products at Various Exhaust Gas Temperatures

Appendix 5

Equilibrium Moistures of Upgraded Products at Various Exhaust Gas Temperatures

	Exhaust Gas Temperature °C	Hot Coal Temperature °C	Product*	Equilibrium Moisture %
Series 1	480	360	0	6.2
			4	6.4
			8	6.1
			H_2O	5.3
Series 2	480	345	0	5.8
			4	6.2
			8	6.6
			H_2O	6.8
Commissioning Experiments	410	255	0	7.9
			4	N.D.
			8	N.D.
			H_2O	9.2
Commissioning Experiments	415	—	0	8.9
			4	9.0
			8	8.2
			H_2O	8.3
Series 3	475	345	0	5.8
			4	6.0
			8	6.4
			H_2O	6.7
Series 4	480	345	0	6.8
			4	6.6
			8	6.6
			H_2O	6.3

* 0, 4, 8 = 0, 4 and 8% moisture products Nitrogen or CO_2 cooled.
H_2O = water cooled products.

Appendix 6

CANMET Oxygen Sorption Data

LABORATORY EVALUATION OF AUTO-OXIDATION OF COAL AT AMBIENT CONDITIONS BY THE STATIC ABSORPTION METHOD

Basic Data:

Cylinder # = 3

Cylinder Volume (mL) = 21,732

Test Sample (g) = 1500

Initial Head Gas Volume (mL) = 20,629

% Oxygen in Air = 20.93

% Nitrogen in Air = 79.07

Oxygen Absorption Observations:

Sample #- 8852-1

Test Time (hrs) = 96

Date Produced- N/A

Date Analysed- March 3, 1989

Head Gas Constituent	Final Result in PPM
Oxygen	110,584
Nitrogen	885,717
Methane	5.48
Carbon Monoxide	1,116.15
Carbon Dioxide	2,574.95

Oxygen Absorption = 153.0 mL/100 g

LABORATORY EVALUATION OF AUTO-OXIDATION OF COAL AT AMBIENT CONDITIONS BY THE STATIC ABSORPTION METHOD

Basic Data:

Cylinder # = 5

Cylinder Volume (mL) = 21,595

Test Sample (g) = 1500

Initial Head Gas Volume (mL) = 20,492

% Oxygen in Air = 20.93

% Nitrogen in Air = 79.07

Oxygen Absorption Observations:

Sample #- OBED - 350°

Test Time (hrs) = 96

Date Produced-

Date Analysed- March 3, 1989

Head Gas Constituent	Final Result in PPM
Oxygen	145,697
Nitrogen	850,283
Methane	5.55
Carbon Monoxide	1,946.45
Carbon Dioxide	2,067.26

Oxygen Absorption = 102.0 mL/100 g

LABORATORY EVALUATION OF AUTO-OXIDATION OF COAL AT AMBIENT CONDITIONS BY THE STATIC ABSORPTION METHOD

Basic Data:

Cylinder # = 6

Cylinder Volume (mL) = 21,793

Test Sample (g) = 1500

Initial Head Gas Volume (mL) = 20,690

% Oxygen in Air = 20.93

% Nitrogen in Air = 79.07

Oxygen Absorption Observations:

Sample #- 8852-1-0

Test Time (hrs) = 96

Date Produced- N/A

Date Analysed- March 6, 1989

Head Gas Constituent	Final Result in PPM
Oxygen	161,318
Nitrogen	836,835
Methane	4.24
Carbon Monoxide	1,091.88
Carbon Dioxide	751.51

Oxygen Absorption = 79.0 mL/100 g

LABORATORY EVALUATION OF AUTO-OXIDATION OF COAL AT AMBIENT CONDITIONS BY THE STATIC ABSORPTION METHOD

Basic Data:

Cylinder # = 4

Cylinder Volume (mL) = 21,671

Test Sample (g) = 1500

Initial Head Gas Volume (mL) = 20,568

% Oxygen in Air = 20.93

% Nitrogen in Air = 79.07

Oxygen Absorption Observations:

Sample #- 8852-1-4

Test Time (hrs) = 96

Date Produced- N/A

Date Analysed- March 13, 1989

Head Gas Constituent	Final Result in PPM
Oxygen	138,137
Nitrogen	857,769
Methane	5.05
Carbon Monoxide	368.25
Carbon Dioxide	3,720.32

Oxygen Absorption = 113.0 mL/100 g

LABORATORY EVALUATION OF AUTO-OXIDATION OF COAL AT AMBIENT CONDITIONS BY THE STATIC ABSORPTION METHOD

Basic Data:

Cylinder # = 5

Cylinder Volume (mL) = 21,595

Test Sample (g) = 1500

Initial Head Gas Volume (mL) = 20,492

% Oxygen in Air = 20.93

% Nitrogen in Air = 279.07

Oxygen Absorption Observations:

Sample #- 8852-1-8

Test Time (hrs) = 96

Date Produced- N/A

Date Analysed- March 13, 1989

Head Gas Constituent	Final Result in PPM
Oxygen	86,883.40
Nitrogen	907,747
Methane	8.35
Carbon Monoxide	401.12
Carbon Dioxide	4,932.75

Oxygen Absorption = 183.0 mL/100 g

LABORATORY EVALUATION OF AUTO-OXIDATION OF COAL AT AMBIENT CONDITIONS BY THE STATIC ABSORPTION METHOD

Basic Data:

Cylinder # = 1

Cylinder Volume (mL) = 21,435

Test Sample (g) = 1500

Initial Head Gas Volume (mL) = 20,332

% Oxygen in Air = 20.93

% Nitrogen in Air = 79.07

Oxygen Absorption Observations:

Sample #- 8852-CO_2-H_2O

Test Time (hrs) = 96

Date Produced- N/A

Date Analysed- April 14, 1989

Head Gas Constituent	Final Result in PPM
Oxygen	155,389
Nitrogen	836,349
Methane	3.12
Carbon Monoxide	246.80
Carbon Dioxide	8,012

Oxygen Absorption = 85.0 mL/100 g

LABORATORY EVALUATION OF AUTO-OXIDATION OF COAL AT AMBIENT CONDITIONS BY THE STATIC ABSORPTION METHOD

Basic Data:

Cylinder # = 2

Cylinder Volume (mL) = 21,235

Test Sample (g) = 1500

Initial Head Gas Volume (mL) = 20,132

% Oxygen in Air = 20.93

% Nitrogen in Air = 79.07

Oxygen Absorption Observations:

Sample #- 8852-CO_2-0

Test Time (hrs) = 96

Date Produced- N/A

Date Analysed- April 14, 1989

Head Gas Constituent	Final Result in PPM
Oxygen	158,107
Nitrogen	792,612
Methane	-
Carbon Monoxide	274.70
Carbon Dioxide	48,999.53

Oxygen Absorption = 69.0 mL/100 g

LABORATORY EVALUATION OF AUTO-OXIDATION OF COAL AT AMBIENT CONDITIONS BY THE STATIC ABSORPTION METHOD

Basic Data:

Cylinder # = 1

Cylinder Volume (mL) = 21,435

Test Sample (g) = 1500

Initial Head Gas Volume (mL) = 20,332

% Oxygen in Air = 20.93

% Nitrogen in Air = 79.07

Oxygen Absorption Observations:

Sample #- 8852-S-H_2O

Test Time (hrs) = 96

Date Produced- N/A

Date Analysed- April 24, 1989

Head Gas Constituent	Final Result in PPM
Oxygen	101,920
Nitrogen	893,222
Methane	4.26
Carbon Monoxide	1,139.74
Carbon Dioxide	3,713.22

Oxygen Absorption = 162.0mL/100 g

LABORATORY EVALUATION OF AUTO-OXIDATION OF COAL AT AMBIENT CONDITIONS BY THE STATIC ABSORPTION METHOD

Basic Data:

Cylinder # = 2

Cylinder Volume (mL) = 21,235

Test Sample (g) = 1500

Initial Head Gas Volume (mL) = 20,132

% Oxygen in Air = 20.93

% Nitrogen in Air = 79.07

Oxygen Absorption Observations:

Sample #- 8852-S-0

Test Time (hrs) = 96

Date Produced- N/A

Date Analysed- April 24, 1989

Head Gas Constituent	Final Result in PPM
Oxygen	164,449
Nitrogen	834,379
Methane	3.49
Carbon Monoxide	942.23
Carbon Dioxide	227.07

Oxygen Absorption = 72.0 mL/100 g

LABORATORY EVALUATION OF AUTO-OXIDATION OF COAL AT AMBIENT CONDITIONS BY THE STATIC ABSORPTION METHOD

Basic Data:

Cylinder # = 3

Cylinder Volume (mL) = 21,732

Test Sample (g) = 1500

Initial Head Gas Volume (mL) = 20,529

% Oxygen in Air = 20.93

% Nitrogen in Air = 79.07

Oxygen Absorption Observations:

Sample #- 8852-SCO_2-CO_2

Test Time (hrs) = 96

Date Produced- N/A

Date Analysed- April 24, 1989

Head Gas Constituent	Final Result in PPM
Oxygen	140,490
Nitrogen	827,196
Methane	4.41
Carbon Monoxide	1,311.21
Carbon Dioxide	30,998.87

Oxygen Absorption = 103.0 mL/100 g

LABORATORY EVALUATION OF AUTO-OXIDATION OF COAL AT AMBIENT CONDITIONS BY THE STATIC ABSORPTION METHOD

Basic Data:

Cylinder # = 4

Cylinder Volume (mL) = 21,671

Test Sample (g) = 1500

Initial Head Gas Volume (mL) = 20,568

% Oxygen in Air = 20.93

% Nitrogen in Air = 79.07

Oxygen Absorption Observations:

Sample #- 8852-SCO_2-H_2O

Test Time (hrs) = 96

Date Produced- N/A

Date Analysed- April 24, 1989

Head Gas Constituent	Final Result in PPM
Oxygen	151,112
Nitrogen	835,843
Methane	4.04
Carbon Monoxide	834.10
Carbon Dioxide	12,205.03

Oxygen Absorption = 91.0 mL/100 g

LABORATORY EVALUATION OF AUTO-OXIDATION OF COAL AT AMBIENT CONDITIONS BY THE STATIC ABSORPTION METHOD

Basic Data:

Cylinder # = 1

Cylinder Volume (mL) = 21,435

Test Sample (g) = 1500

Initial Head Gas Volume (mL) = 20,332

% Oxygen in Air = 20.93

% Nitrogen in Air = 79.07

Oxygen Absorption Observations:

Sample #- 8852-CO_2-4

Test Time (hrs) = 96

Date Produced- N/A

Date Analysed- May 4, 1989

Head Gas Constituent	Final Result in PPM
Oxygen	187,247
Nitrogen	804,644
Methane	2.48
Carbon Monoxide	411.91
Carbon Dioxide	7,696.88

Oxygen Absorption = 34.0 mL/100 g

LABORATORY EVALUATION OF AUTO-OXIDATION OF COAL AT AMBIENT CONDITIONS BY THE STATIC ABSORPTION METHOD

Basic Data:

Cylinder # = 1

Cylinder Volume (mL) = 21,435

Test Sample (g) = 1500

Initial Head Gas Volume (mL) = 20,332

% Oxygen in Air = 20.93

% Nitrogen in Air = 79.07

Oxygen Absorption Observations:

Sample #- 8852-CO_2-4

Test Time (hrs) = 96

Date Produced-

Date Analysed- May 8, 1989

Head Gas Constituent	Final Result in PPM
Oxygen	187,247
Nitrogen	804,644
Methane	2.48
Carbon Monoxide	411.91
Carbon Dioxide	2,696.88

Oxygen Absorption = 34.0 mL/100 g

LABORATORY EVALUATION OF AUTO-OXIDATION OF COAL AT AMBIENT CONDITIONS BY THE STATIC ABSORPTION METHOD

Basic Data:

Cylinder # = 2

Cylinder Volume (mL) = 21,235

Test Sample (g) = 1500

Initial Head Gas Volume (mL) = 20,132

% Oxygen in Air = 20.93

% Nitrogen in Air = 79.07

Oxygen Absorption Observations:

Sample #- 8852-CO_2-8

Test Time (hrs) = 96

Date Produced- N/A

Date Analysed- May 8, 1989

Head Gas Constituent	Final Result in PPM
Oxygen	156,122
Nitrogen	837,466
Methane	2.76
Carbon Monoxide	448.27
Carbon Dioxide	5,933.55

Oxygen Absorption = 83.0 mL/100 g

LABORATORY EVALUATION OF AUTO-OXIDATION OF COAL AT AMBIENT CONDITIONS BY THE STATIC ABSORPTION METHOD

Basic Data:

Cylinder # = 3

Cylinder Volume (mL) = 21,732

Test Sample (g) = 1500

Initial Head Gas Volume (mL) = 20,629

% Oxygen in Air = 20.93

% Nitrogen in Air = 79.07

Oxygen Absorption Observations:

Sample #- 8852-SCO_2-4

Test Time (hrs) = 96

Date Produced- N/A

Date Analysed- May 15, 1989

Head Gas Constituent	Final Result in PPM
Oxygen	154,224
Nitrogen	835,867
Methane	2.95
Carbon Monoxide	785.40
Carbon Dioxide	9,120.27

Oxygen Absorption = 87.0 mL/100 g

LABORATORY EVALUATION OF AUTO-OXIDATION OF COAL AT AMBIENT CONDITIONS BY THE STATIC ABSORPTION METHOD

Basic Data:

Cylinder # = 4

Cylinder Volume (mL) = 21,671

Test Sample (g) = 1500

Initial Head Gas Volume (mL) = 20,568

% Oxygen in Air = 20.93

% Nitrogen in Air = 79.07

Oxygen Absorption Observations:

Sample #- 8852-SCO_2-8

Test Time (hrs) = 96

Date Produced- N/A

Date Analysed- May 15, 1989

Head Gas Constituent	Final Result in PPM
Oxygen	170,852
Nitrogen	818,135
Methane	2.60
Carbon Monoxide	641.49
Carbon Dioxide	10,370.55

Oxygen Absorption = 61.0 mL/100 g

LABORATORY EVALUATION OF AUTO-OXIDATION OF COAL AT AMBIENT CONDITIONS BY THE STATIC ABSORPTION METHOD

Basic Data:

Cylinder # = 2

Cylinder Volume (mL) = 21,235

Test Sample (g) = 1500

Initial Head Gas Volume (mL) = 20,132

% Oxygen in Air = 20.93

% Nitrogen in Air = 79.07

Oxygen Absorption Observations:

Sample #- $52\text{-}CO_2\text{-}0$

Test Time (hrs) = 96

Date Produced- N/A

Date Analysed- June 5, 1989

Head Gas Constituent	Final Result in PPM
Oxygen	145,327
Nitrogen	812,763
Methane	3.16
Carbon Monoxide	1,192.36
Carbon Dioxide	40,711.83

Oxygen Absorption = 91.0 mL/100 g

LABORATORY EVALUATION OF AUTO-OXIDATION OF COAL AT AMBIENT CONDITIONS BY THE STATIC ABSORPTION METHOD

Basic Data:

Cylinder # = 3

Cylinder Volume (mL) = 21,732

Test Sample (g) = 1500

Initial Head Gas Volume (mL) = 20,629

% Oxygen in Air = 20.93

% Nitrogen in Air = 79.07

Oxygen Absorption Observations:

Sample #- 52-S-0

Test Time (hrs) = 96

Date Produced- N/A

Date Analysed- June 5, 1989

Head Gas Constituent	Final Result in PPM
Oxygen	164,855
Nitrogen	833,581
Methane	3.10
Carbon Monoxide	1,007.11
Carbon Dioxide	553.46

Oxygen Absorption = 73.0 mL/100 g

LABORATORY EVALUATION OF AUTO-OXIDATION OF COAL AT AMBIENT CONDITIONS BY THE STATIC ABSORPTION METHOD

Basic Data:

Cylinder # = 4

Cylinder Volume (mL) = 21,671

Test Sample (g) = 1500

Initial Head Gas Volume (mL) = 50,568

% Oxygen in Air = 20.93

% Nitrogen in Air = 79.07

Oxygen Absorption Observations:

Sample #- 52-S-H_2O

Test Time (hrs) = 96

Date Produced- N/A

Date Analysed- June 5, 1989

Head Gas Constituent	Final Result in PPM
Oxygen	154,581
Nitrogen	842,797
Methane	3.41
Carbon Monoxide	769.09
Carbon Dioxide	1,850.38

Oxygen Absorption = 89.0 mL/100 g

LABORATORY EVALUATION OF AUTO-OXIDATION OF COAL AT AMBIENT CONDITIONS BY THE STATIC ABSORPTION METHOD

Basic Data:

Cylinder # = 5

Cylinder Volume (mL) = 21,595

Test Sample (g) = 1500

Initial Head Gas Volume (mL) = 20,492

% Oxygen in Air = 20.93

% Nitrogen in Air = 79.07

Oxygen Absorption Observations:

Sample #- 52-S-CO_2-H_2O

Test Time (hrs) = 96

Date Produced- N/A

Date Analysed- June 5, 1989

Head Gas Constituent	Final Result in PPM
Oxygen	136,040
Nitrogen	856,210
Methane	4.75
Carbon Monoxide	926.60
Carbon Dioxide	6,818.30

Oxygen Absorption = 114.0 mL/100 g

LABORATORY EVALUATION OF AUTO-OXIDATION OF COAL AT AMBIENT CONDITIONS BY THE STATIC ABSORPTION METHOD

Basic Data:

Cylinder # = 3

Cylinder Volume (mL) = 21,671

Test Sample (g) = 1500

Initial Head Gas Volume (mL) = 20,629

% Oxygen in Air = 20.93

% Nitrogen in Air = 79.07

Oxygen Absorption Observations:

Sample #- 8852-M23-CO_2-4

Test Time (hrs) = 96

Date Produced- May 23, 1989

Date Analysed- June 9, 1989

Head Gas Constituent	Final Result in PPM
Oxygen	137,578.1
Nitrogen	829,349.9
Methane	3.88
Carbon Monoxide	795.86
Carbon Dioxide	32,267.36

Oxygen Absorption = 108.0 mL/100 g

LABORATORY EVALUATION OF AUTO-OXIDATION OF COAL AT AMBIENT CONDITIONS BY THE STATIC ABSORPTION METHOD

Basic Data:

Cylinder # = 4

Cylinder Volume (mL) = 21,671

Test Sample (g) = 1500

Initial Head Gas Volume (mL) = 20,568

% Oxygen in Air = 20.93

% Nitrogen in Air = 79.07

Oxygen Absorption Observations:

Sample #- 8852-M23-CO_2-8

Test Time (hrs) = 96

Date Produced- May 23, 1989

Date Analysed- June 9, 1989

Head Gas Constituent	Final Result in PPM
Oxygen	117,576.2
Nitrogen	856,570.6
Methane	3.52
Carbon Monoxide	807.33
Carbon Dioxide	25,042.27

Oxygen Absorption = 138.0 mL/100 g

LABORATORY EVALUATION OF AUTO-OXIDATION OF COAL AT AMBIENT CONDITIONS BY THE STATIC ABSORPTION METHOD

Basic Data:

Cylinder # = 1

Cylinder Volume (mL) = 21,435

Test Sample (g) = 1475

Initial Head Gas Volume (mL) = 20,350

% Oxygen in Air = 20.93

% Nitrogen in Air = 79.07

Oxygen Absorption Observations:

Sample #- 8852-M23-S-8

Test Time (hrs) = 96

Date Produced- May 23, 1989

Date Analysed- June 19, 1989

Head Gas Constituent	Final Result in PPM
Oxygen	165,390.9
Nitrogen	831,717.4
Methane	2.43
Carbon Monoxide	544.79
Carbon Dioxide	2,320.96

Oxygen Absorption = 73.0 mL/100 g

LABORATORY EVALUATION OF AUTO-OXIDATION OF COAL AT AMBIENT CONDITIONS BY THE STATIC ABSORPTION METHOD

Basic Data:

Cylinder # = 5

Cylinder Volume (mL) = 21,595

Test Sample (g) = 1466

Initial Head Gas Volume (mL) = 20,517

% Oxygen in Air = 20.93

% Nitrogen in Air = 79.07

Oxygen Absorption Observations:

Sample #- 8852-M23-S-4

Test Time (hrs) = 96

Date Produced- May 23, 1989

Date Analysed- June 9, 1989

Head Gas Constituent	Final Result in PPM
Oxygen	165,697.6
Nitrogen	830,654.9
Methane	2.20
Carbon Monoxide	593.92
Carbon Dioxide	3,051.20

Oxygen Absorption = 73.0 mL/100 g

LABORATORY EVALUATION OF AUTO-OXIDATION OF COAL AT AMBIENT CONDITIONS BY THE STATIC ABSORPTION METHOD

Basic Data:

Cylinder # = 1

Cylinder Volume (mL) = 21,435

Test Sample (g) = 1500

Initial Head Gas Volume (mL) = 20,332

% Oxygen in Air = 20.93

% Nitrogen in Air = 79.07

Oxygen Absorption Observations:

Sample #- 52-O-JL4-F

Test Time (hrs) = 96

Date Produced- July 4, 1989

Date Analysed- July 10, 1989

Head Gas Constituent	Final Result in PPM
Oxygen	72,132.65
Nitrogen	924,915.9
Methane	8.74
Carbon Monoxide	1,254.25
Carbon Dioxide	1,665.18

Oxygen Absorption = 200.0 mL/100 g

LABORATORY EVALUATION OF AUTO-OXIDATION OF COAL AT AMBIENT CONDITIONS BY THE STATIC ABSORPTION METHOD

Basic Data:

Cylinder # = 2

Cylinder Volume (mL) = 21,235

Test Sample (g) = 1500

Initial Head Gas Volume (mL) = 20,132

% Oxygen in Air = 20.93

% Nitrogen in Air = 79.07

Oxygen Absorption Observations:

Sample #- 52-O-JL4-1

Test Time (hrs) = 96

Date Produced- July 4, 1989

Date Analysed- July 10, 1989

Head Gas Constituent	Final Result in PPM
Oxygen	157,202
Nitrogen	842,109.6
Methane	7.81
Carbon Monoxide	341.55
Carbon Dioxide	328.07

Oxygen Absorption = 83.0 mL/100 g

LABORATORY EVALUATION OF AUTO-OXIDATION OF COAL AT AMBIENT CONDITIONS BY THE STATIC ABSORPTION METHOD

Basic Data:

Cylinder # = 3

Cylinder Volume (mL) = 21,732

Test Sample (g) = 1500

Initial Head Gas Volume (mL) = 20,629

% Oxygen in Air = 20.93

% Nitrogen in Air = 79.07

Oxygen Absorption Observations:

Sample #- 52-O-JL4-2

Test Time (hrs) = 96

Date Produced- July 4, 1989

Date Analysed- July 10, 1989

Head Gas Constituent	Final Result in PPM
Oxygen	126,449.5
Nitrogen	871,658.8
Methane	7.41
Carbon Monoxide	481.12
Carbon Dioxide	1,358.67

Oxygen Absorption = 130.0 mL/100 g

LABORATORY EVALUATION OF AUTO-OXIDATION OF COAL AT AMBIENT CONDITIONS BY THE STATIC ABSORPTION METHOD

Basic Data:

Cylinder # = 4

Cylinder Volume (mL) = 21,671

Test Sample (g) = 1500

Initial Head Gas Volume (mL) = 20,568

% Oxygen in Air = 20.93

% Nitrogen in Air = 79.07

Oxygen Absorption Observations:

Sample #- 52-JL6-0

Test Time (hrs) = 96

Date Produced- July 6, 1989

Date Analysed- July 14, 1989

Head Gas Constituent	Final Result in PPM
Oxygen	138,950.4
Nitrogen	807,665
Methane	4.96
Carbon Monoxide	1,908.08
Carbon Dioxide	51,462.74

Oxygen Absorption = 101.0 mL/100 g

LABORATORY EVALUATION OF AUTO-OXIDATION OF COAL AT AMBIENT CONDITIONS BY THE STATIC ABSORPTION METHOD

Basic Data:

Cylinder # = 5

Cylinder Volume (mL) = 21,595

Test Sample (g) = 1500

Initial Head Gas Volume (mL) = 20,492

% Oxygen in Air = 20.93

% Nitrogen in Air = 79.07

Oxygen Absorption Observations:

Sample #- 52-O-JL6-H_2O

Test Time (hrs) = 96

Date Produced- July 6, 1989

Date Analysed- July 14, 1989

Head Gas Constituent	Final Result in PPM
Oxygen	144,604.6
Nitrogen	833,385.8
Methane	9.89
Carbon Monoxide	1,024.58
Carbon Dioxide	20,943.61

Oxygen Absorption = 99.0 mL/100 g

LABORATORY EVALUATION OF AUTO-OXIDATION OF COAL AT AMBIENT CONDITIONS BY THE STATIC ABSORPTION METHOD

Basic Data:

Cylinder # = 1

Cylinder Volume (mL) = 21,435

Test Sample (g) = 1500

Initial Head Gas Volume (mL) = 20,332

% Oxygen in Air = 20.93

% Nitrogen in Air = 79.07

Oxygen Absorption Observations:

Sample #- 52-O-JL4-1-8

Test Time (hrs) = 96

Date Produced- July 4, 1989

Date Analysed- July 18, 1989

Head Gas Constituent	Final Result in PPM
Oxygen	129,444.8
Nitrogen	865,662.7
Methane	10.29
Carbon Monoxide	1,790.15
Carbon Dioxide	3,068.33

Oxygen Absorption = 124.0 mL/100 g

LABORATORY EVALUATION OF AUTO-OXIDATION OF COAL AT AMBIENT CONDITIONS BY THE STATIC ABSORPTION METHOD

Basic Data:

Cylinder # = 2

Cylinder Volume (mL) = 21,235

Test Sample (g) = 1500

Initial Head Gas Volume (mL) = 20,132

% Oxygen in Air = 20.93

% Nitrogen in Air = 79.07

Oxygen Absorption Observations:

Sample #- 52-0-JL4-1-4

Test Time (hrs) = 96

Date Produced- July 4, 1989

Date Analysed- July 18, 1989

Head Gas Constituent	Final Result in PPM
Oxygen	158,090.1
Nitrogen	838,621.3
Methane	7.52
Carbon Monoxide	1,473.53
Carbon Dioxide	1,750.74

Oxygen Absorption = 82.0 mL/100 g

LABORATORY EVALUATION OF AUTO-OXIDATION OF COAL AT AMBIENT CONDITIONS BY THE STATIC ABSORPTION METHOD

Basic Data:

Cylinder # = 5

Cylinder Volume (mL) = 21,595

Test Sample (g) = 1500

Initial Head Gas Volume (mL) = 20,492

% Oxygen in Air = 20.93

% Nitrogen in Air = 79.07

Oxygen Absorption Observations:

Sample #- 52-JL6-0-4

Test Time (hrs) = 96

Date Produced- July 6, 1989

Date Analysed- July 18, 1989

Head Gas Constituent	Final Result in PPM
Oxygen	129,391.1
Nitrogen	821,514.1
Methane	4.76
Carbon Monoxide	1,792.86
Carbon Dioxide	47,279.4

Oxygen Absorption = 116.0 mL/100 g

LABORATORY EVALUATION OF AUTO-OXIDATION OF COAL AT AMBIENT CONDITIONS BY THE STATIC ABSORPTION METHOD

Basic Data:

Cylinder # = 6

Cylinder Volume (mL) = 21,793

Test Sample (g) = 1500

Initial Head Gas Volume (mL) = 20,690

% Oxygen in Air = 20.93

% Nitrogen in Air = 79.07

Oxygen Absorption Observations:

Sample #- 52-JL6-0-8

Test Time (hrs) = 96

Date Produced- July 6, 1989

Date Analysed- July 18, 1989

Head Gas Constituent	Final Result in PPM
Oxygen	115,083.9
Nitrogen	834,403.4
Methane	5.89
Carbon Monoxide	1,744.05
Carbon Dioxide	48,658.95

Oxygen Absorption = 139.0 mL/100 g

LABORATORY EVALUATION OF AUTO-OXIDATION OF COAL AT AMBIENT CONDITIONS BY THE STATIC ABSORPTION METHOD

Basic Data:

Cylinder # = 1

Cylinder Volume (mL) = 21,435

Test Sample (g) = 1500

Initial Head Gas Volume (mL) = 20,332

% Oxygen in Air = 20.93

% Nitrogen in Air = 79.07

Oxygen Absorption Observations:

Sample #- 52-O-JL2-Steam

Test Time (hrs) = 96

Date Produced- July 2, 1989

Date Analysed- July 31, 1989

Head Gas Constituent	Final Result in PPM
Oxygen	184,322.3
Nitrogen	814,330.2
Methane	3.77
Carbon Monoxide	861.10
Carbon Dioxide	481.72

Oxygen Absorption = 42.0 mL/100 g

LABORATORY EVALUATION OF AUTO-OXIDATION OF COAL AT AMBIENT CONDITIONS BY THE STATIC ABSORPTION METHOD

Basic Data:

Cylinder # = 2

Cylinder Volume (mL) = 21,235

Test Sample (g) = 1500

Initial Head Gas Volume (mL) = 20,132

% Oxygen in Air = 20.93

% Nitrogen in Air = 79.07

Oxygen Absorption Observations:

Sample #- 52-O-JL12-ST + H_2O

Test Time (hrs) = 96

Date Produced- July 12, 1989

Date Analysed- July 31, 1989

Head Gas Constituent	Final Result in PPM
Oxygen	185,067.4
Nitrogen	813,624
Methane	4.19
Carbon Monoxide	629.09
Carbon Dioxide	673.32

Oxygen Absorption = 40.0 mL/100 g

LABORATORY EVALUATION OF AUTO-OXIDATION OF COAL AT AMBIENT CONDITIONS BY THE STATIC ABSORPTION METHOD

Basic Data:

Cylinder # = 1

Cylinder Volume (mL) = 21,435

Test Sample (g) = 1500

Initial Head Gas Volume (mL) = 20,332

% Oxygen in Air = 20.93

% Nitrogen in Air = 79.07

Oxygen Absorption Observations:

Sample #- 52-JL12-4

Test Time (hrs) = 96

Date Produced- July 12, 1989

Date Analysed- August 8, 1989

Head Gas Constituent	Final Result in PPM
Oxygen	183,364.6
Nitrogen	814,951.9
Methane	3.07
Carbon Monoxide	501.78
Carbon Dioxide	1,178.05

Oxygen Absorption = 43.0 mL/100 g

LABORATORY EVALUATION OF AUTO-OXIDATION OF COAL AT AMBIENT CONDITIONS BY THE STATIC ABSORPTION METHOD

Basic Data:

Cylinder # = 2

Cylinder Volume (mL) = 21,235

Test Sample (g) = 1500

Initial Head Gas Volume (mL) = 20,132

% Oxygen in Air = 20.93

% Nitrogen in Air = 79.07

Oxygen Absorption Observations:

Sample #- 52-JL12-8

Test Time (hrs) = 96

Date Produced- July 12, 1989

Date Analysed- August 8, 1989

Head Gas Constituent	Final Result in PPM
Oxygen	153,754
Nitrogen	843,629.9
Methane	3.95
Carbon Monoxide	587.03
Carbon Dioxide	2,007.66

Oxygen Absorption = 88.0 mL/100 g

LABORATORY EVALUATION OF AUTO-OXIDATION OF COAL AT AMBIENT CONDITIONS BY THE STATIC ABSORPTION METHOD

Basic Data:

Cylinder # = 3

Cylinder Volume (mL) = 21,732

Test Sample (g) = 1500

Initial Head Gas Volume (mL) = 20,629

% Oxygen in Air = 20.93

% Nitrogen in Air = 79.07

Oxygen Absorption Observations:

Sample #- 52-JL13-0

Test Time (hrs) = 96

Date Produced- July 13, 1989

Date Analysed- August 8, 1989

Head Gas Constituent	Final Result in PPM
Oxygen	187,278.7
Nitrogen	806,956.8
Methane	3.03
Carbon Monoxide	682
Carbon Dioxide	5,078.98

Oxygen Absorption = 36.0 mL/100 g

LABORATORY EVALUATION OF AUTO-OXIDATION OF COAL AT AMBIENT CONDITIONS BY THE STATIC ABSORPTION METHOD

Basic Data:

Cylinder # = 4

Cylinder Volume (mL) = 21,671

Test Sample (g) = 1500

Initial Head Gas Volume (mL) = 20,568

% Oxygen in Air = 20.93

% Nitrogen in Air = 79.07

Oxygen Absorption Observations:

Sample #- 52-JL13-4

Test Time (hrs) = 96

Date Produced- July 13, 1989

Date Analysed- August 8, 1989

Head Gas Constituent	Final Result in PPM
Oxygen	186,142.4
Nitrogen	805,360.2
Methane	2.82
Carbon Monoxide	436.81
Carbon Dioxide	8,056.77

Oxygen Absorption = 37.0 mL/100 g

LABORATORY EVALUATION OF AUTO-OXIDATION OF COAL AT AMBIENT CONDITIONS BY THE STATIC ABSORPTION METHOD

Basic Data:

Cylinder # = 5

Cylinder Volume (mL) = 21,595

Test Sample (g) = 1500

Initial Head Gas Volume (mL) = 20,492

% Oxygen in Air = 20.93

% Nitrogen in Air = 79.07

Oxygen Absorption Observations:

Sample #- 52-JL13-8

Test Time (hrs) = 96

Date Produced- July 13, 1989

Date Analysed- August 8, 1989

Head Gas Constituent	Final Result in PPM
Oxygen	171,399.3
Nitrogen	820,614.3
Methane	3.68
Carbon Monoxide	530.39
Carbon Dioxide	7,451.66

Oxygen Absorption = 60.0 mL/100 g

LABORATORY EVALUATION OF AUTO-OXIDATION OF COAL AT AMBIENT CONDITIONS BY THE STATIC ABSORPTION METHOD

Basic Data:

Cylinder # = 6

Cylinder Volume (mL) = 21,793

Test Sample (g) = 1500

Initial Head Gas Volume (mL) = 20,690

% Oxygen in Air = 20.93

% Nitrogen in Air = 79.07

Oxygen Absorption Observations:

Sample #- 52-O-JL13-ST + H_2O

Test Time (hrs) = 96

Date Produced- July 13, 1989

Date Analysed- August 8, 1989

Head Gas Constituent	Final Result in PPM
Oxygen	191,068.3
Nitrogen	806,874.6
Methane	2.89
Carbon Monoxide	478.92
Carbon Dioxide	1,574.72

Oxygen Absorption = 31.0mL/100 g